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SEMIANNUAL REPORT

DESIGN, DEVELOPMENT, FABRICATION, TEST AND DELIVERY OF ELECTROTHERMAL ENGINE SYSTEMS

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Technical Management
NASA Lewis Research Center
Cleveland, Ohio
Electric Propulsion Office
Henry Hunczak

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ABSTRACT

This document is the semi-annual report on a program for the design, development, fabrication, test, and delivery of an electrothermal three-axis attitude control and four-directional station-keeping system. The basic electrothermal propulsion element is a fast heat-up ammonia-fueled resistojet which operates at a thrust level of 400 micropounds, specific impulse of 150 seconds, and a power level of less than 10 watts. The three-axis control system includes contract logic, power- and signal-conditioning packages, and an ammonia propellant fuel and storage system. The deliverble, hardware, which is to be flight-quality welded-cordwood construction has been designed and prototype units are in the final stages of fabrication.

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I. INTRODUCTION

A. PROGRAM OBJECTIVES

The overall objective of the present program is to design, develop, and fabricate a flight-quality, ammonia-fueledresistojet thrustor system. The thrustor system is defined to include logic controls, power and signal conditioning, and a zero-gravity propellant feed system. The system is to be suitable for the three-axis control and four-directional station keeping of satellites in the 1000-pound class. The thrustors are of the resistojet, fast heat-up type; the nominal thrust is 0.40×10^{-3} pounds, and the specific impulse is greater than a minimum of 150 seconds.

B. PROGRAM ORGANIZATION

This program originates from the Electric Propulsion Office of the NASA, Lewis Research Center. Mr. Henry Hunczak is the NASA Lewis Research Center Project Manager. The Project Director at Avco/SSD is Dr. R. R. John. The other participants in the program and their principal areas of contribution are: Mr. J. Olbrych, Mr. M. Lambert, and Mr. L. Smith, Electronic System Design and Development; Mr. R. Cybulski, Mr. W. Davis, Mr. K. Pugmire, and Mr. E. Comfort, Thrustor and Propellant Feed System Design, Development and Evaluation; Mr. A. Buczynski, Quality Assurance.

C. PROGRAM SCHEDULING

This is the semiannual report on Contract NAS 3-7934 entitled Design, Development, Fabrication, Test, and Delivery of Electrothermal Engine Systems and covers the period from December 1965 through June 1966.

D. TECHNICAL SUMMARY

A three-axis attitude control and four-directional station-keeping system, which makes use of a fast heat-up resistojet as the basic propulsion element has been designed and is in the final stages of fabrication and evaluation. The thrustors operate at a nominal thrust of 0.40×10^{-3} pounds, a specific impulse of 150 seconds, and require less than 7.5 watts of input power when they are operational. The attitude control system has separate control logic and power- and signal-conditioning packages for each axis. The control logic system has been designed to make it possible to adjust the basic control circuit parameters including hysteresis between thrust-off and thrust-on and the lead-network time constant. A sensor has also been provided for each axis. Station-keeping units, each containing two thrustors, have been provided for two of the three axes.

A breadboard package has been completed and checked out for the electronic circuitry. The deliverable hardware, which is to be of flight-quality welded-cordwood construction, has been designed and prototype units are in the final stages of fabrication.

A zero-gravity ammonia propellant storage and feed system has been developed and is being fabricated. The storage supply will have a 57-pound capacity. The fast heat-up thrustor to be used on the three-axis will be fabricated from rhenium. A prototype thrustor has been fabricated and is being evaluated. Considerable difficulty has been encountered in finding a low power (< 0.50-watt) valve suitable for use with ammonia. The current choice is a valve manufactured by the Carleton Valve Company of East Aurora, New York.

The total system power requirement will, of course, depend on the total system duty cycle. However, when it is operational, each axis will require less than 10 watts of input power; similarly, each station-keeping thrustor will require less than 10 watts power. Thus, in the exceptional situation when all three axis and the station-keeping thrustors are operational, the total instantaneous power input will be less than 50 watts.

II. CURRENT STATUS OF THREE-AXIS RESISTOJET CONTROL SYSTEM

A. INTRODUCTION AND BACKGROUND

The purpose of the present program is to design, develop, and fabricate a flight-quality, ammonia-fueled resistojet thrustor system. The thrustor system is defined to include logic controls, power and signal conditioning, and a zero-gravity propellant feed system. The system is further defined to include all the parts and components required for three-axis attitude control and two-direction station-keeping of a stable-platform type satellite. The thrustors for the thrustor system are of the fast heat-up type, similar to those developed under a previous contract (NAS 3-5908); the nominal thrust is 0.40×10^{-3} pounds, and the specific impulse is to be a minimum of 150 seconds. Provision has been made for operating the thrustor system either hot or cold. The system includes a zero-gravity propellant feed system with an ammonia storage capacity of 57 pounds. A separate attitude control logic system has been provided for each axis; the control logic system contains the equipment necessary to accept analog type signals from the attitude sensor and to provide separate thrust-on and thrust-off signals to the two thrustor controls which maintain the angular attitude of the spacecraft. Finally, a three-axis sensor and light source system have been provided for checkout of the complete three-axis system on the air-bearing table at NASA, Lewis Research Center.

The following sections present a description of the Power, Signal and Control Logic System, the Propellant Storage and Feed System, and the Thrustor System.

B. POWER, SIGNAL AND CONTROL LOGIC SYSTEMS

1. General Description

A schematic diagram of the overall electronics system is shown in Figure 1. The position of the test bed or spacecraft with respect to a fixed light source is monitored by means of the light sensor. In the flight case, there would be a light source, e.g., star, horizon, etc., and sensor for each axis; in the present case, however, a special sensor has been designed for use on the NASA, Lewis three-axis air bearing table. This sensor only requires a single light source. The signals from the light sensor are then transmitted to the control logic package for the appropriate axis. Each axis has a junction box; the junction box, as shown in Figure 1, has provision for mounting a control logic module, a power-and signal-conditioning module a station-keeping module, and a propellant feed system signal conditioner. For simplicity in fabrication, the junction boxes for each of the three axes are identical. As shown in Figure 1, there is, however, only one propellant signal-conditioning module and only two station-keeping modules for the total three-axis system.

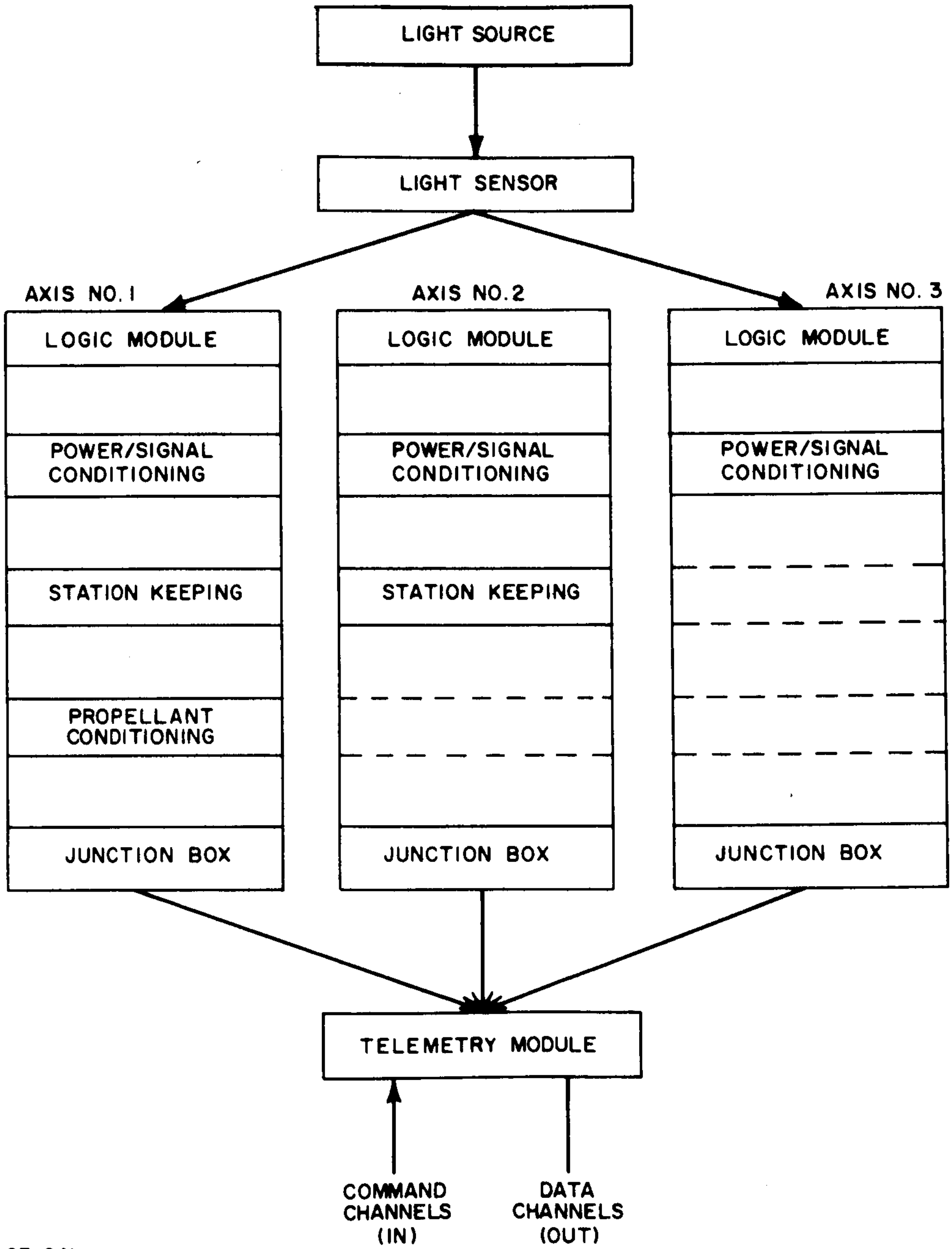

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Figure 1 SCHEMATIC DIAGRAM OF THE OVERALL ELECTRONICS SYSTEM

As indicated, there is a separate control logic system for each axis. The control logic system has been designed to make it possible to adjust the basic control circuit parameters. Provision for these adjustments has been incorporated into a separate adjustment box. During system development tests, either on an analog computer or the test table, the adjustment box can be used instead of the junction box. For simplicity, the extra adjustment box is considered a piece of test equipment and is not flight-quality hardware. The test procedure, as presently contemplated, would be to determine the optimum control logic module parameters, i.e., lead-network time constants and hysteresis, on the basis of laboratory system tests. The resistors and capacitors which establish the optimum control logic parameters would then be incorporated permanently into the flight hardware. The flight-quality junction box has provision for receiving the different electrical components required to adjust the control logic parameters.

2. Control Logic System

A functional diagram of the control logic system is shown in Figure 2. The control function, Z (t), is generated by the lead network. The lead network takes the sensor signal, Z (t), and generates a control function, Z (t), which is proportional to the sum of the vehicle position, θ (t), and rate, $\dot{\theta}$ (t). The lead network has been described previously.[1] As shown in Figure 2, the control function, θ (t) is the fed into a switching network which controls the operation of the appropriate engine.

The basic switching network is shown in Figure 3. The control method for the control logic system is simply one in which the thrustor is operated continuously as long as a specified angular error is exceeded. The control logic systems for the different axes operate completely separately from each other; there are no interconnections between the individual axes. Referring to Figure 3, the input signal from the sensor passes through the lead-lag network and then simultaneously through an absolute magnitude detector and a ploraity detector. If the signal from the absolute magnitude detector (and hence from the lead-lag network and the sensor) is above a certain level, it will trigger the Schmitt Trigger and send a +5-volt digital signal out of the package. The polarity detector provides two digital outputs. One of the outputs is at +5 volts whenever the input signal is positive, and at 0 volts whenever the input signal is negative; the second output is +5 volts whenever the input signal is negative, and at 0 volts whenever the input signal is negative. The Schmitt trigger actuates the valve-heater circuit, and the polarity detector signals the appropriate thrustor to go on.

As indicated previously, the basic parameters of the control logic system can be varied by means of an adjustment-junction box. This box is shown in dashed lines. The basic parameters which can be varied by the adjustment box are shown in Table I.

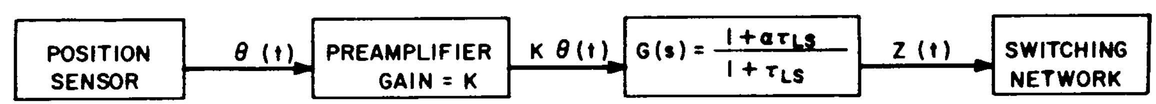

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Figure 2 FUNCTIONAL DIAGRAM OF THE CONTROL LOGIC SYSTEM

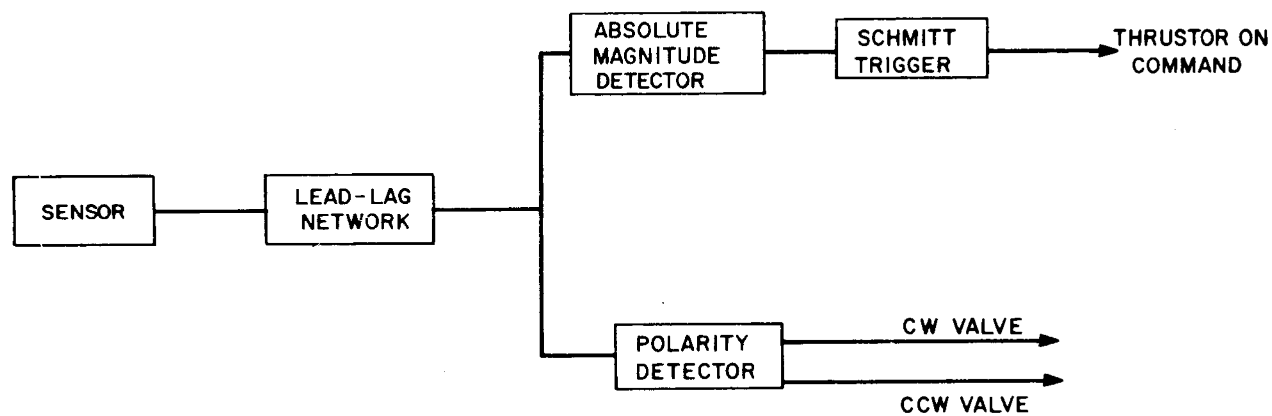

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Figure 3 BASIC CONTROL LOGIC SWITCHING NETWORK

TABLE I

RANGE OF ADJUSTMENTS FOR THE CONTROL LOGIC MODULE

Variable Input Voltage to Switch the Trigger Circuit	$\pm$ 0.10 to $\pm$ 10 volts
Hysteresis Between Thrust-On and Thrust-Off	5 to 40 percent
Lead-Network Time Constant	2 to 100 seconds

The basic trigger level of the Schmitt triggers is held constant, while the voltage divider, shown in the adjustment box, is adjustable to permit triggering at sensor input levels (0-rate) from $\pm$ 0.1 volt to $\pm$ 10 volts. For example, an angular displacement of $\pm$ 1 degree might correspond to $\pm$ 0.1 volt on one sensor and $\pm$ 10 volts on another sensor; the variable voltage divider makes it possible to accommodate a wide variety of sensors.

To avoid control logic instabilities, it is found necessary to incorporate an adjustment for hysteresis between the thrust-on and the thrust-off signal voltage level. The turn-off level may be externally adjusted from 5 to 40 percent lower than the turn-on level. There are a total of eight selections for hysteresis.

The significant transfer function of the control logic system is that of a lead network for stabilization and a lag or upper frequency rolloff for noise attenuation. The lead or lower frequency time constant is adjustable in approximately 12 discrete steps from 2 to 100 seconds. The lag or upper frequency rolloff time constant is variable to $\pm$ 10 percent of the adjustment time constant. Provision is also included to operate with two discrete values of the transfer function damping factor, i.e., $\alpha = 0.10$ and 0.033.

The inputs and outputs from the control logic module are summarized in Table II and Figure 4.

As shown in Figure 4, the output signals for angular position and rate, are passed directly to the telemetry package; the thrustor on-command and thrustor selection are passed directly to the power- and signal-conditioning package.

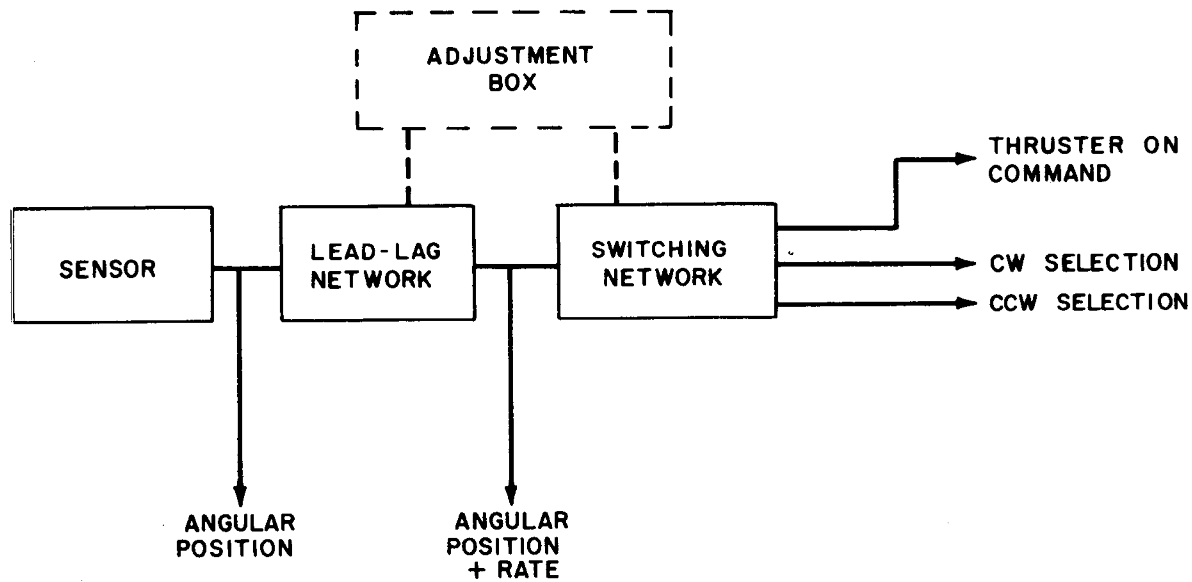

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Figure 4 FUNCTIONAL DESCRIPTION OF THE CONTROL LOGIC PACKAGE

TABLE II

INPUT AND OUTPUT CHANNELS FOR THE CONTROL LOGIC MODULE

Input Channels
1. 28 volt ± 10-percent Battery Power
2. Sensor Input (± 0.10 to ± 10 volts)
Output Channels
1. Angular Position, θ
2. Angular Position + Rate, $\theta + \dot{\theta}$ (analog)
3. Thrustor on Command (Schmitt Trigger)
4. CW Engine Selection (Polarity Detector)
5. CCW Engine Selection (Polarity Detector)
6. Battery Current for Single-Axis Operation

The model specifications for the control logic module are presented in Appendix A.

3. Power and Signal Conditioner

The power and signal conditioner contains the necessary circuitry to supply power to the resistojet heater elements and to monitor engine performance. A schematic diagram of the basic power and signal conditioning module is shown in Figure 5.

Because of the low resistance of the resistojet heater elements (order of 0.10 ohm), it has been found necessary to convert the basic dc input power to 5000 cps ac and then to step down to the required heater voltage (order of 1 volt) by means of a transformer. A schematic diagram for this operation is shown in Figure 6. The power input to the heater elements is thus alternating rather than direct current. A separate transformer is provided for each heater element.

The power and signal conditioner contains all the necessary circuitry to supply a nominal 7.5 watts to the resistojet heater elements which have a nominal resistance of 0.10 ohm. Referring to Figure 5, the power conditioner operates in the following manner. The proper heater and valve, i.e., clockwise or counter-clockwise, is selected by the + 5-volt signal from the polarity detector in the control logic package. The + 5-volt thrust-on signal from the Schmitt trigger in the logic package activates the oscillator circuitry, thereby turning the heater on. The thrust-on

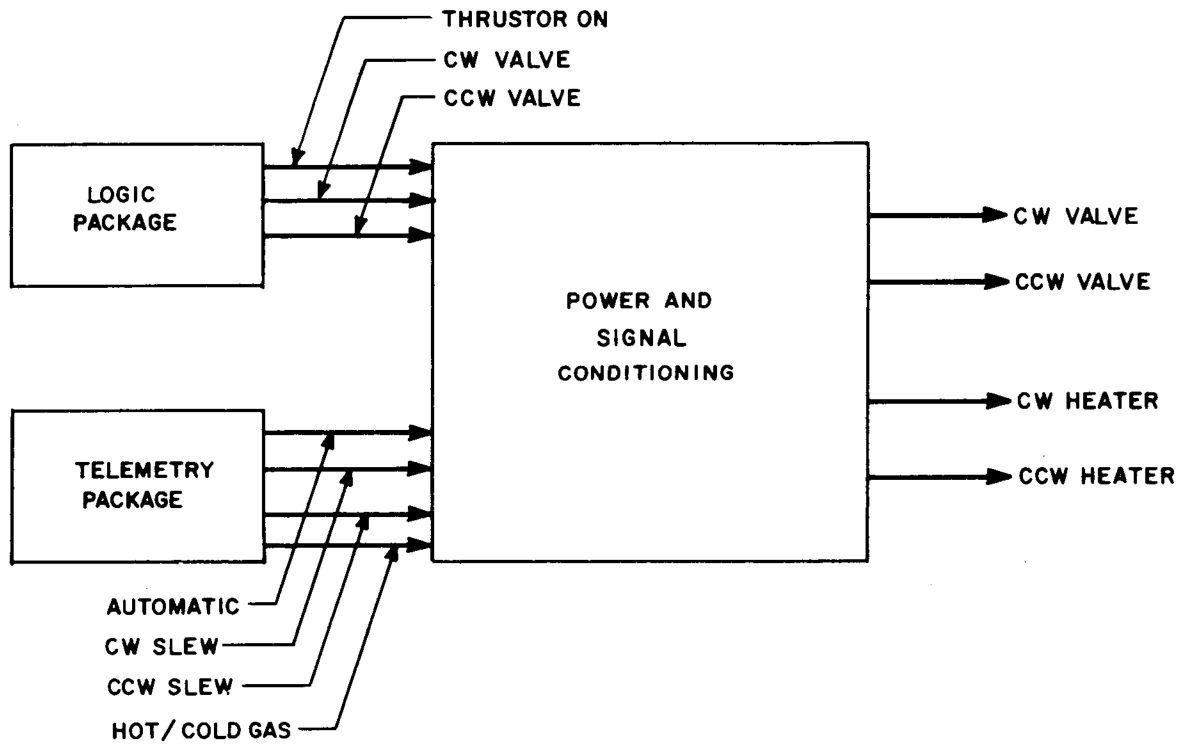

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Figure 5 SCHEMATIC DIAGRAM OF THE BASIC POWER–AND SIGNAL–CONDITIONING PACKAGE

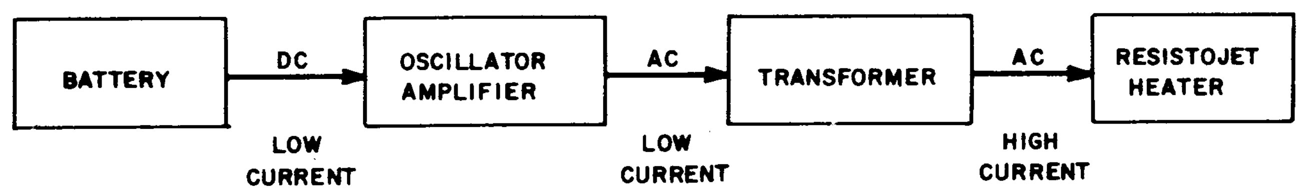

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Figure 6 POWER SUPPLY SCHEMATIC FOR THE RESISTOJET HEATER ELEMENTS

Schmitt trigger signal also activates the gas flow valves 1 second after the heaters are energized. Power transformers are located directely at the thrustors.

Provision is also included in the power-and signal-conditioner package to operate the thrustors without any power to the heater element, i.e., cold operation, and to have manual operation of the clockwise and counter-clockwise thrustors. The input channels for the power- and signal-conditioner package are summarized in Table III.

TABLE III

INPUT CHANNELS FOR THE POWER-AND SIGNAL-CONDITIONING PACKAGE

1. Automatic Command
2. CW Engine Selection (Polarity Detector)
3. CCW Engine Selection (Polarity Detector)
4. Hot/Cold Gas Operation
5. CW Engine - Manual
6. CCW Engine - Manual

The power-and signal-conditioner package also includes provision for monitoring the parameters shown in Table IV.

TABLE IV

PARAMETERS MONITORED BY THE POWER-AND SIGNAL-CONDITIONING PACKAGE

1. CW and CCW Heater Current (Transformer Primary)
2. CW Heater Voltage (Transformer Secondary)
3. CCW Heater Voltage (Transformer Secondary)
4. CW Nozzle Box Pressure
5. CCW Nozzle Box Pressure
6. CW Valve Voltage
7. CCW Valve Voltage

A total of seven signals are monitored from each power- and signal-conditioning package.

The model specifications for the power- and signal-conditioning module are presented in Appendix B.

4. Station-Keeping Package

The station-keeping package contains the necessary circuitry to supply power to the station-keeping module. The station-keeping module is identical to the power- and signal-conditioning module with the exception of the command control function. The station-keeping function is intended to operate on command only. A schematic diagram of the basic station keeping module is shown in Figure 7.

Table V shows the input channels for the station-keeping module.

TABLE V

INPUT CHANNELS FOR THE STATION-KEEPING MODULE

1.	Hot/Cold Gas Operation
2.	CW Thrustor
3.	CCW Thrustor

The output channels are indicated in Table VI.

TABLE VI

OUTPUT CHANNELS FOR THE STATION-KEEPING MODULE

1.	CW and CCW Heater Current (Transformer Primary)
2.	CW Heater Voltage (Transformer Secondary)
3.	CCW Heater Voltage (Transformer Secondary)
4.	CW Nozzle Box Pressure
5.	CCW Nozzle Box Pressure
6.	CW Valve Voltage
7.	CCW Valve Voltage

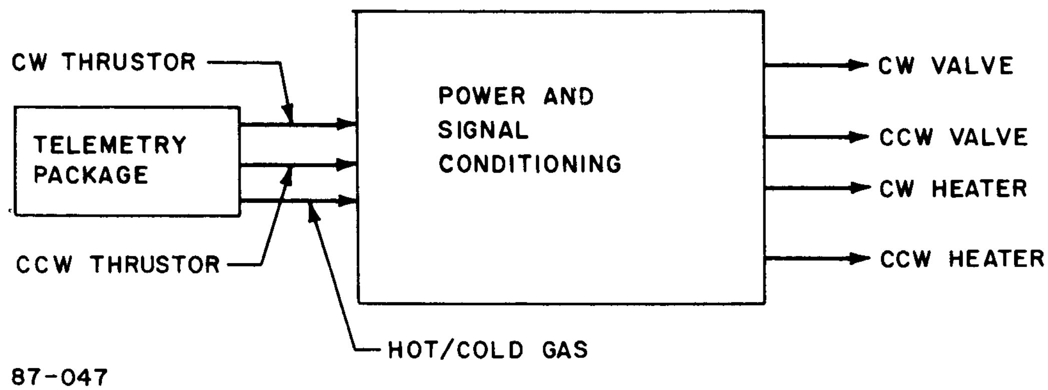

Figure 7 SCHEMATIC DIAGRAM OF THE STATION-KEEPING MODULE

As in the case of the power-and signal-conditioning package there are a total of seven output channels.

The model specifications for the station-keeping package are presented in Appendix C.

5. Propellant Storage Signal Conditioner

A schematic diagram of the propellant storage signal conditioner is shown in Figure 8. The propellant storage signal conditioner monitors the information shown in Table VII.

TABLE VII

OUTPUT CHANNELS FOR THE PROPELLANT CONDITIONER

1. Propellant Supply Pressure
2. Plenum Pressure
3. Plenum Differential Pressure
4. Pressure Switch

The model specifications for the supply signal conditioning package are presented in Appendix D.

6. Three-Axis Sensor and Light Source

The angle sensor is an instrument which senses angular deviations of the test table from a three-axis coordinate system. The output signals are in the form of dc electric voltages that are linearly proportional to the angular deviation. The signals are polarized so that a positive voltage is developed for a positive deviation and a negative voltage for a negative deviation.

The light source is shown in Figures 9 and 10. The source consists of an incandescent lamp, a condensing lens assembly, an illuminated aperture, and a projection lens that has its principal focal point at the illuminated circular aperture.

The sensor consists of a highly corrected lens that receives the beam of light from the light source and focuses an image of the illuminated aperture in the light source on to a quadrant of silicon light-sensitive cells. Angular motions of the sensor, with respect to the light source, result

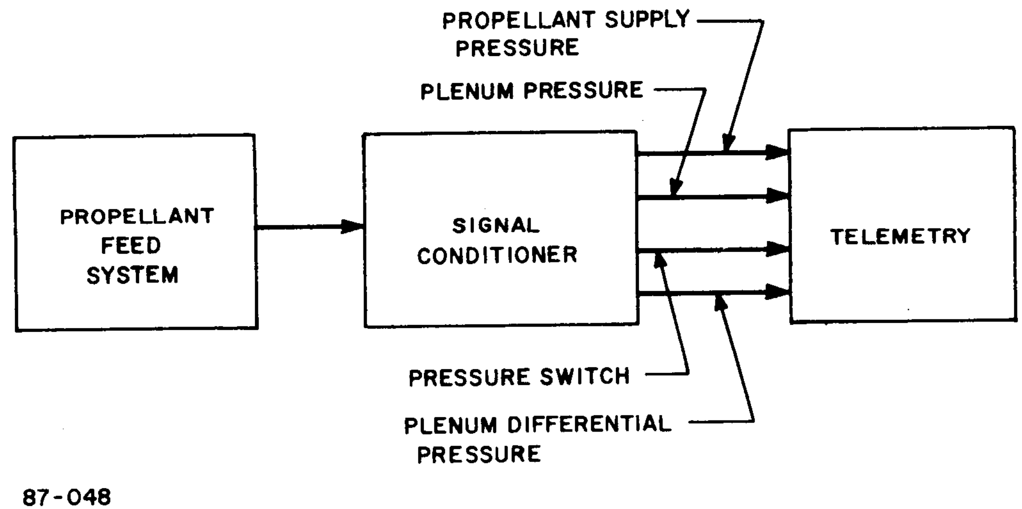

Figure 8 SCHEMATIC DIAGRAM OF THE PROPELLANT FEED SYSTEM SIGNAL CONDITIONER

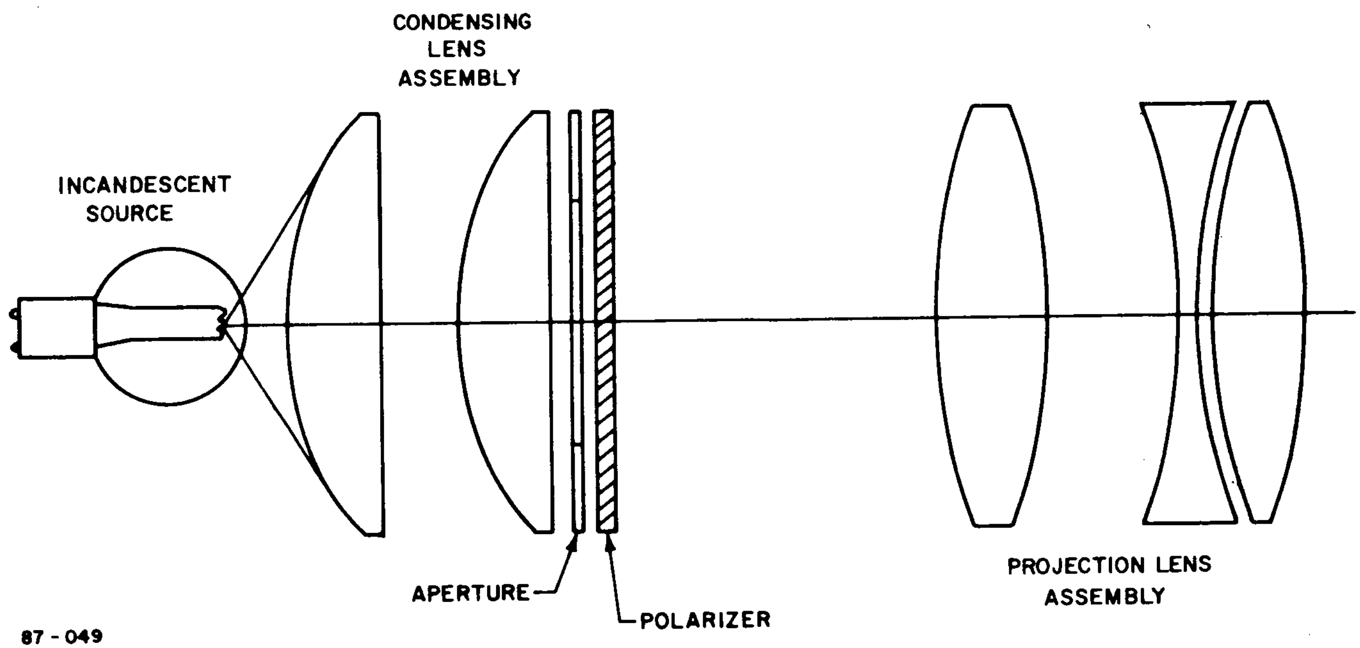

Figure 9 SCHEMATIC DIAGRAM OF THE LIGHT SOURCE

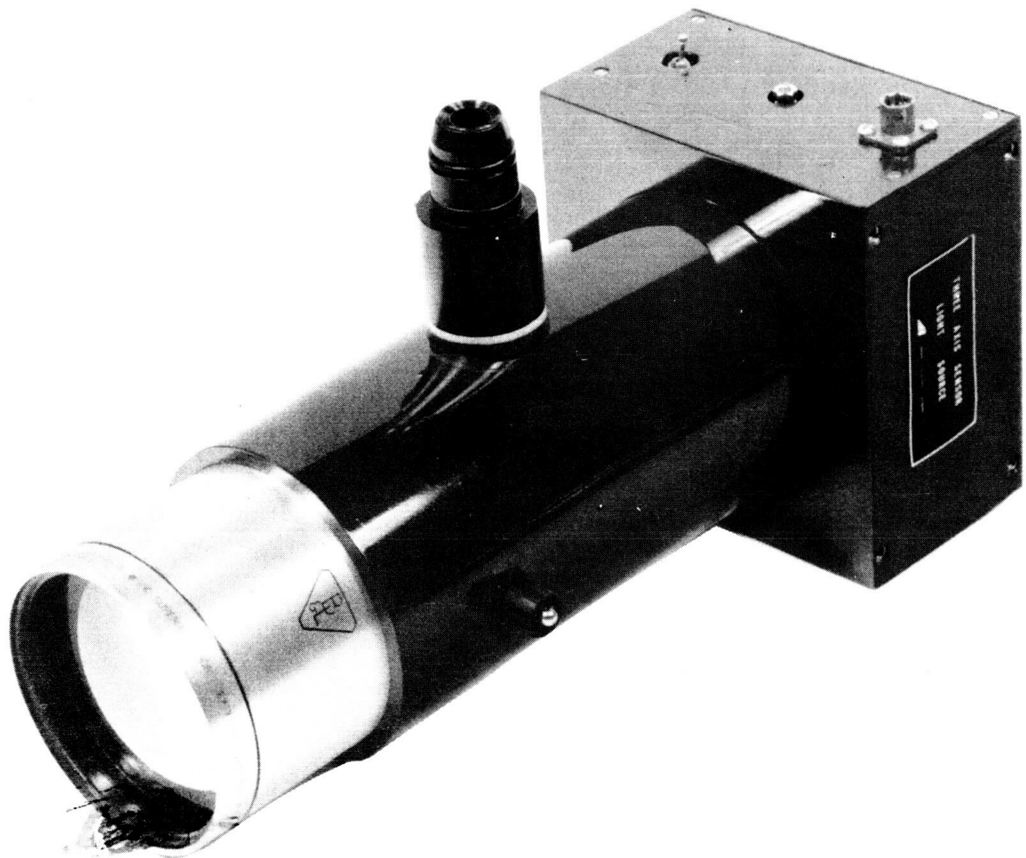

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Figure 10 PHOTOGRAPH OF THE LIGHT SOURCE in a displacement of the circular image on the quadrant of cells. Each quadrant of the cell assembly is filled with a polarization analyzer to allow rotation about the optic axis to be sensed. The output of the cells are in turn fed to groups of solid-state amplifiers in a logic circuit that permits the angular deviation of each axis to be separated.

The basic sensor optics are shown in Figure 11. The detector assembly is shown in Figure 12. When the optical axis of the sensor is parallel to the optical axis of the light source, the circular image is centered on the detector assembly and each cell receives an equal amount of illumination. As the sensor is rotated about either axis that is normal to the source line of sight, the image is displaced with respect to the center of the detector array. If the sensor is rotated about its optical axis, then the image is not displaced from the center of the detector assembly, but instead rotates about the optical axis. The polarization vector then approaches coincidence with two diagonally opposite polarization analyzers and approaches orthogonality on the other two analyzers. Therefore, the intensity of illumination on two cells increases while there is a corresponding decrease in the other two cells. These effects are illustrated in Figure 13. Finally, Figures 14 and 15 show the sensor output versus angular displacement for respectiveiy the X, Y, and Z axis.

7. Summary of Command Input and Output Channels for the Power, Signal and Control Logic System

A summary of the command input channels which pass into the telemetry package is presented in Table VIII.

TABLE VIII

COMMAND INPUT CHANNELS TO THE TELEMETRY PACKAGE - SUMMARY

Channel Number	Description
1	Power On/Off
2	All Axes on Automatic
3	Pitch-Axis CW Slew On/Off
4	Pitch-Axis CCW Slew On/Off

TABLE VIII (Concl'd)

Channel Number	Description
5	Yaw-Axis CW Slew On/Off
6	Yaw-Axis CCW Slew On/Off
7	Roll-Axis CW Slew On/Off
8	Roll-Axis CW Slew On/Off
9	North Station Keeping On/Off
10	South Station Keeping On/Off
11	East Station Keeping On/Off
12	West Station Keeping On/Off
13	Pitch-Axis Hot Gas Operation On/Off
14	Yaw-Axis Hot Gas Operation On/Off
15	Roll-Axis Hot Gas Operation On/Off
16	North-South Station Keeping Hot Gas Operation On/Off
17	East-West Station Keeping Hot Gas Operation On/Off

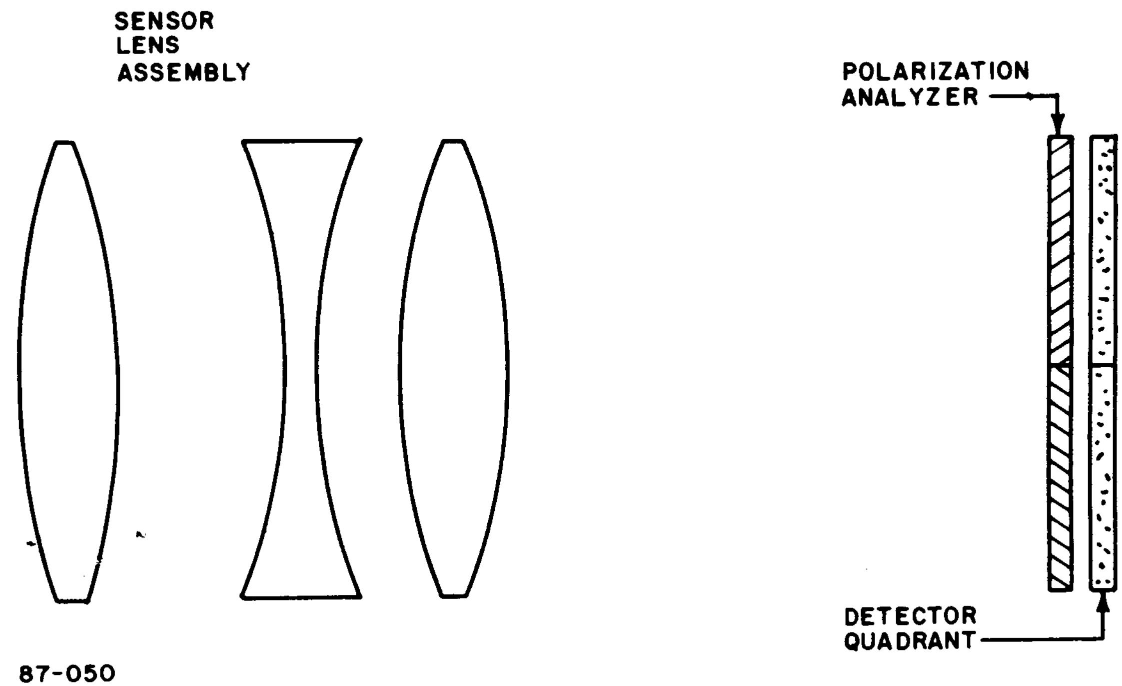

Figure 11 SCHEMATIC DIAGRAM OF THE BASIC SENSOR OPTICS

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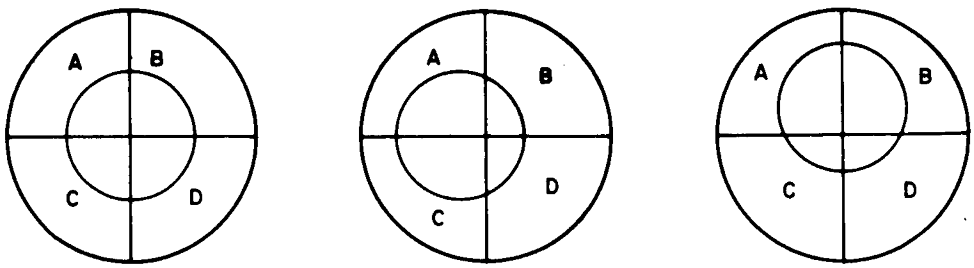
Figure 12 PHOTOGRAPH OF THE BASIC LIGHT SENSOR

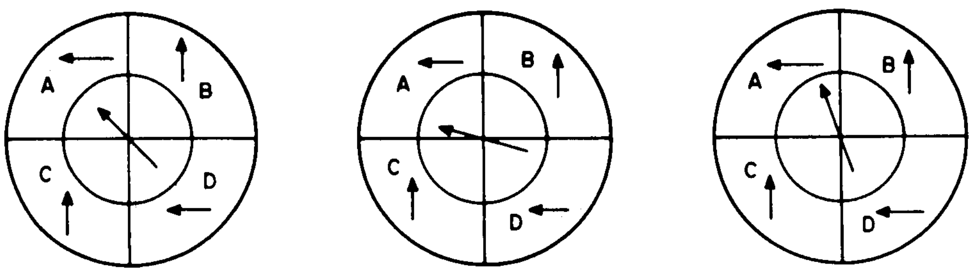
DETECTOR LOGIC
X, Y AXES



0 DISPLACEMENT			+ X DISPLACEMENT			+ Y DISPLACEMENT		
CELL		OUTPUT	CELL		OUTPUT	CELL		OUTPUT
A	=	k	A	=	k+Δ	A	=	k+Δ
B	=	k	B	=	k−Δ	B	=	k+Δ
C	=	k	C	=	k+Δ	C	=	k−Δ
D	=	k	D	=	k−Δ	D	=	k−Δ

Z AXES

ARROWS INDICATE POLARIZATION DIRECTION



CELL		OUTPUT	CELL		OUTPUT	CELL		OUTPUT
A	=	k	A	=	k+Δ	A	=	k−Δ
B	=	k	B	=	k−Δ	B	=	k+Δ
C	=	k	C	=	k−Δ	C	=	k+Δ
D	=	k	D	=	k+Δ	D	=	k−Δ

X OUTPUT $= A + C - B - D = (k+\Delta) + (k+\Delta) - (k-\Delta) - (k-\Delta) = 4\Delta$

Y OUTPUT $= A + B - C - D = 4\Delta$

Z OUTPUT $= A + D - B - C = 4\Delta$

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Figure 13 OPERATION OF THE THREE-AXIS LIGHT SENSOR

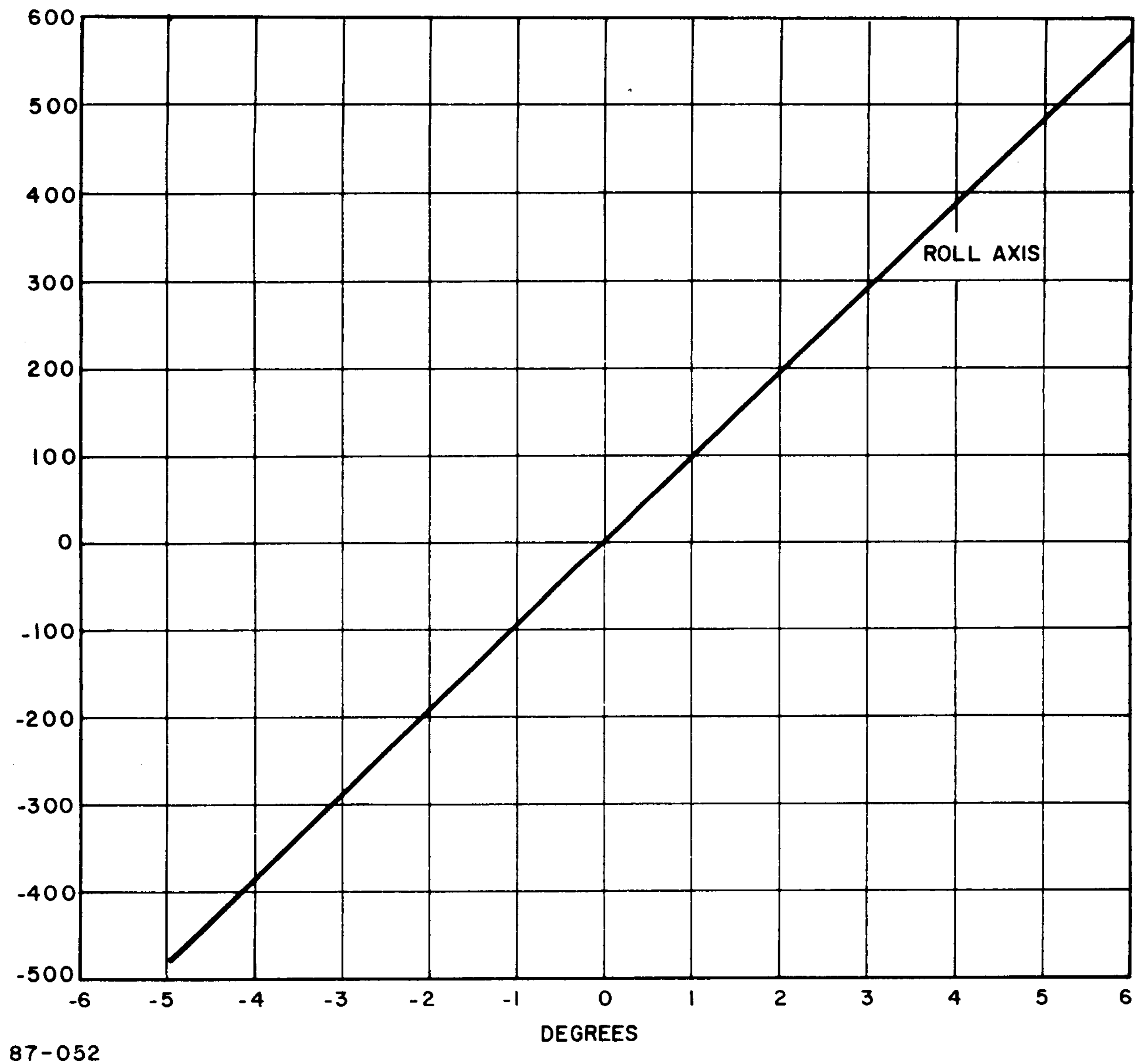

Figure 14 SENSOR OUTPUT VERSUS ANGULAR DISPLACEMENT FOR THE X AND Y AXIS

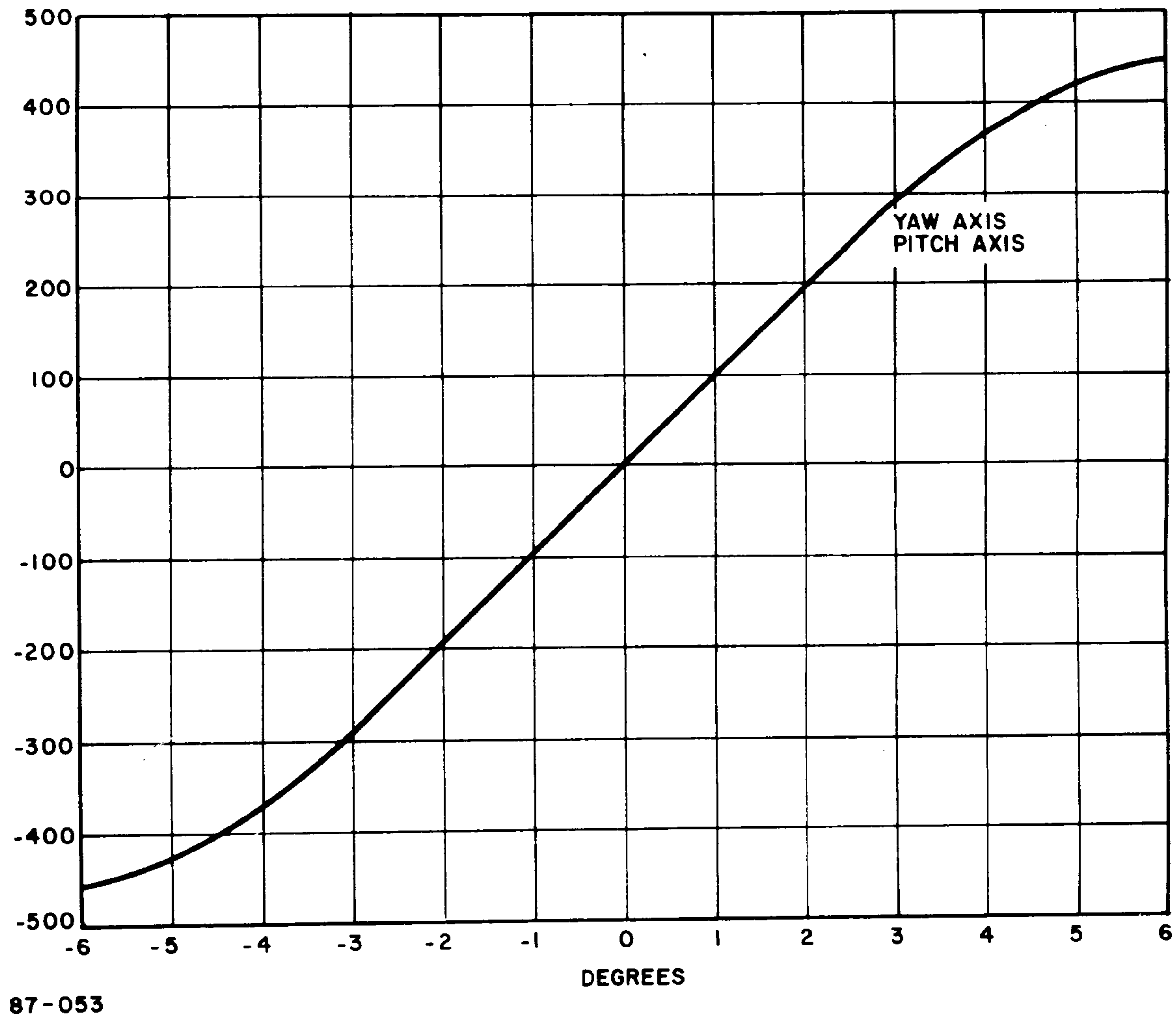

Figure 15 SENSOR OUTPUT VERSUS ANGULAR DISPLACEMENT FOR THE Z AXIS

As indicated there are a total of 17 input channels which can be transmitted into the telemetry package.

A summary of the output channels which pass into the telemetry package is presented in Table IX.

TABLE IX

OUTPUT CHANNELS FROM THE TELEMETRY PACKAGE

Channel Number	Description
Commutated Channels	
1-3	Heater Current for Each Axis (I)
4-6	CW Heater Voltage for Each Axis (I)
7-9	CCW Heater Voltage for Each Axis (I)
10-12	CW Valve Voltage for Each Axis (I)
13-15	CCW Valve Voltage for Each Axis (I)
16-18	CW Nozzle Box Pressure for Each Axis (I)
19-21	CCW Nozzle Box Pressure for Each Axis (I)
22-23	CW Station-Keeping Heater Voltage for Two Axis (I)
24-25	CCW Station-Keeping Heater Voltage for Two Axis (I)
26-27	Station-Keeping Heater Current for Two Axis (I)
28-29	CW Station-Keeping Valve Voltage for Two Axis (I)
30-31	CCW Station-Keeping Valve Voltage for Two Axis (I)

TABLE IX (Concl'd)

Channel Number	
Commutated Channels	Description
32-33	CW Station-Keeping Nozzle Box Pressure for Two Axis (I)
34-35	CCW Station-Keeping Nozzle Box Pressure for Two Axis (I)
36-38	Battery Current for Three Axes (I)
39	Supply Pressure (I)
40	Plenum Temperature (I)
41	Plenum Differential Pressure (I)
Continuous Channels	
42-44	Position Error Voltage for Each Axis (C)
45-47	Position Plus Rate Error Voltage for Each Axis (C)
48	Plenum Pressure
49	Pressure Switch

There are a total of 49 output channels of information from the system. Forty-one channels are commutated, 8 channels are continuous.

C. FABRICATION TECHNIQUE FOR THE ELECTRONIC MODULES

The four basic electronic packages are: (a) Power and Signal Conditioning; (b) Station Keeping; (c) Control Logic; and (d) Propellant Signal Conditioning. These packages have been described in the previous section. A breadboard model of the electronics systems is shown in Figure 16. This breadboard model will be checked out on the single-axis table for possible integration problems with other components of the resistojet system. The final electronics systems to be delivered to NASA, Lewis are, however, to be flight-quality welded-cordwood construction.. A description of the welded-cordwood construction technique is presented below.

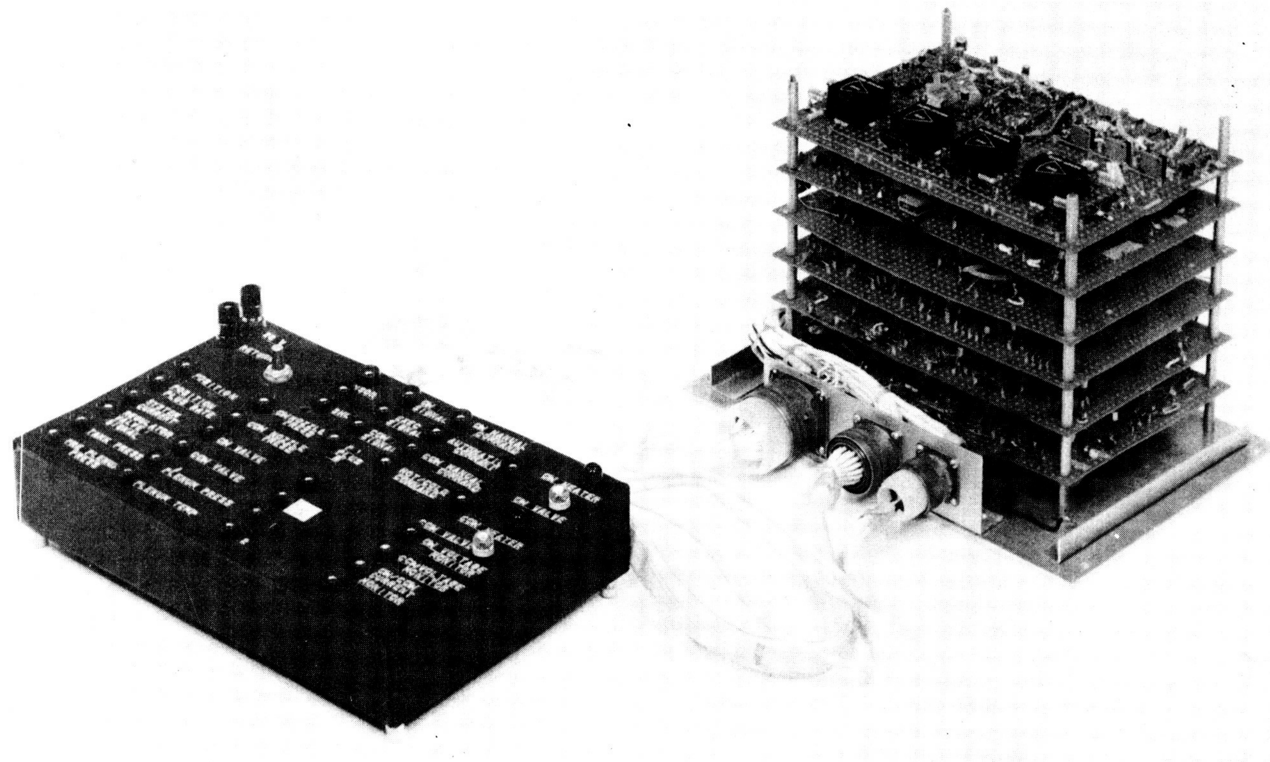

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Figure 16 BREADBOARD PACKAGE FOR THE SINGLE-AXIS SYSTEM INCLUDING CONTROL LOGIC MODULE, POWER AND SIGNAL CONDITIONER, AND PROPELLANT SUPPLY CONDITIONER

Referring to Figure 17, the different electronics packages consists of printed circuit assemblies. A typical printed circuit assembly, in turn, consists of two printed cirucit boards. The welded component assemblies are mounted between the printed circuit boards. The welded component assemblies, in turn, consist of a series of film templates; the individual electronic components are mounted between the film templates.

For illustrative purposes, the fabrication process is shown in Figures 18 through 22. Figure 18 shows the unassemblied components for a typical welded component assembly. As indicated above, the individual components are welded between the film templates. Two film templates are mounted on each side of a welded subassembly. The components are attached to each other by means of the welder shown in Figure 19.

Four typical welded module subassemblies are shown in Figure 20. The welded module subassemblies are mounted between printed circuit boards as shown in Figure 21. Finally, the printed circuit assemblies are mounted together in a package as illustrated in Figure 22.

The welded module assembly drawings have been completed, and a complete prototype welded cordwood package will be finished by 15 September.

D. PROPELLANT STORAGE AND FEED SYSTEM

The basic zero-gravity propellant feed system is shown in Figure 23. An assembly drawing of the system is shown in Figure 24.

Referring to Figure 23, the zero-gravity propellant feed system consists of an ammonia storage tank in which ammonia is stored in both the gaseous and liquid state. The valves, V_1 and V_2 are opened when the pressure in the preplenum falls below the pressure setting on the pressure switches, PS_1 and PS_2. One pressure switch is set slightly below the other pressure switch. Thus, if one valve fails closed the other will then open. A critical feature of the design is the preplenum chamber and orifice which are located immediately downstream of the main plenum chamber. By suitably adjusting the orifice diameter and size of the preplenum, it is possible to hold the plenum pressure to less than ± 5 percent with either gas or liquid flowing into the preplenum. The zero-gravity propellant concept has been utilized previously in the fabrication of a resistojet satellite inversion system for the ATS satellite.

The critical components in the zero-gravity ammonia propellant feed system are shown in Table X.

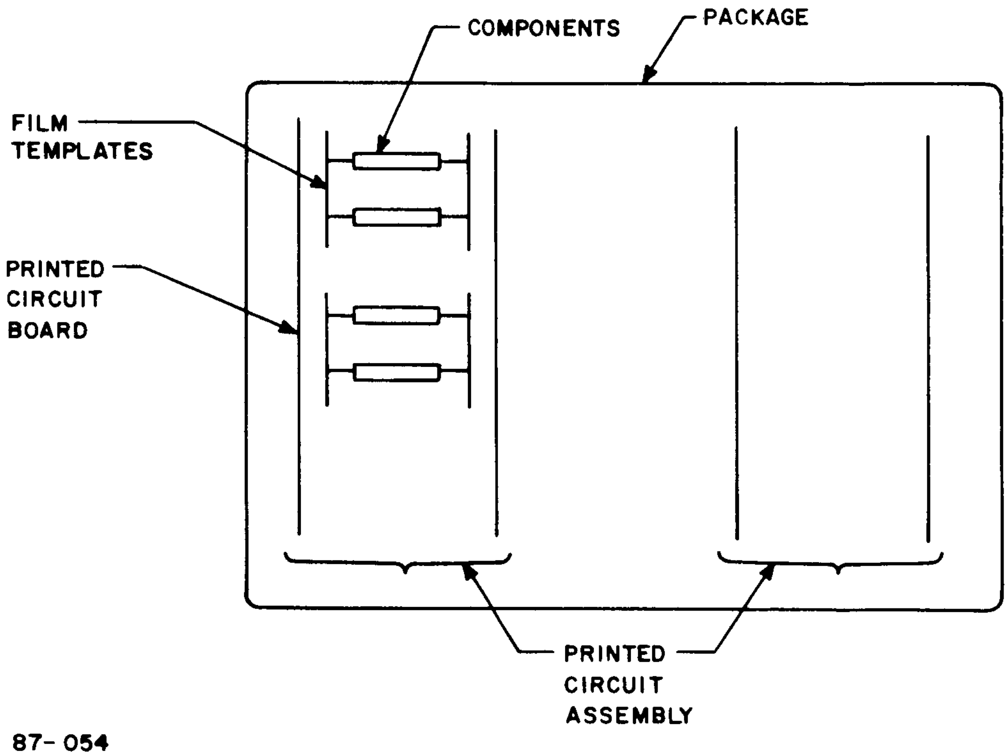

Figure 17 SCHEMATIC DIAGRAM OF A TYPICAL ELECTRONICS PACKAGE

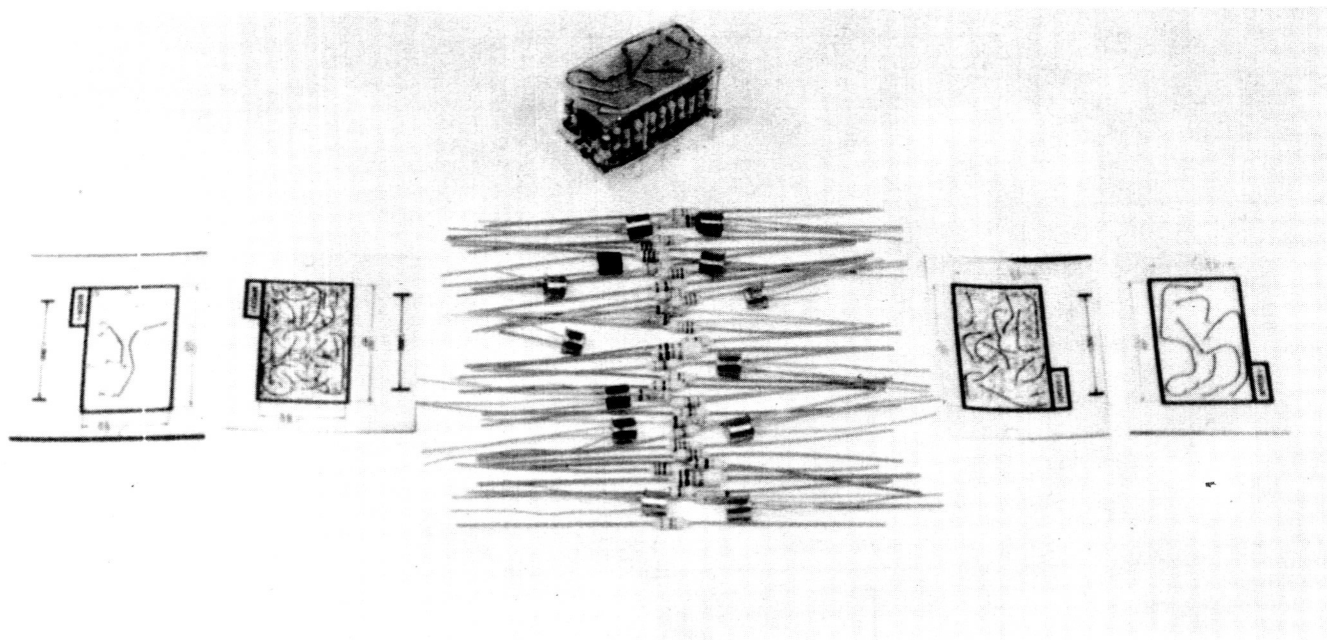

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Figure 18 UNASSEMBLED COMPONENTS FOR A TYPICAL WELDED MODULE ASSEMBLY

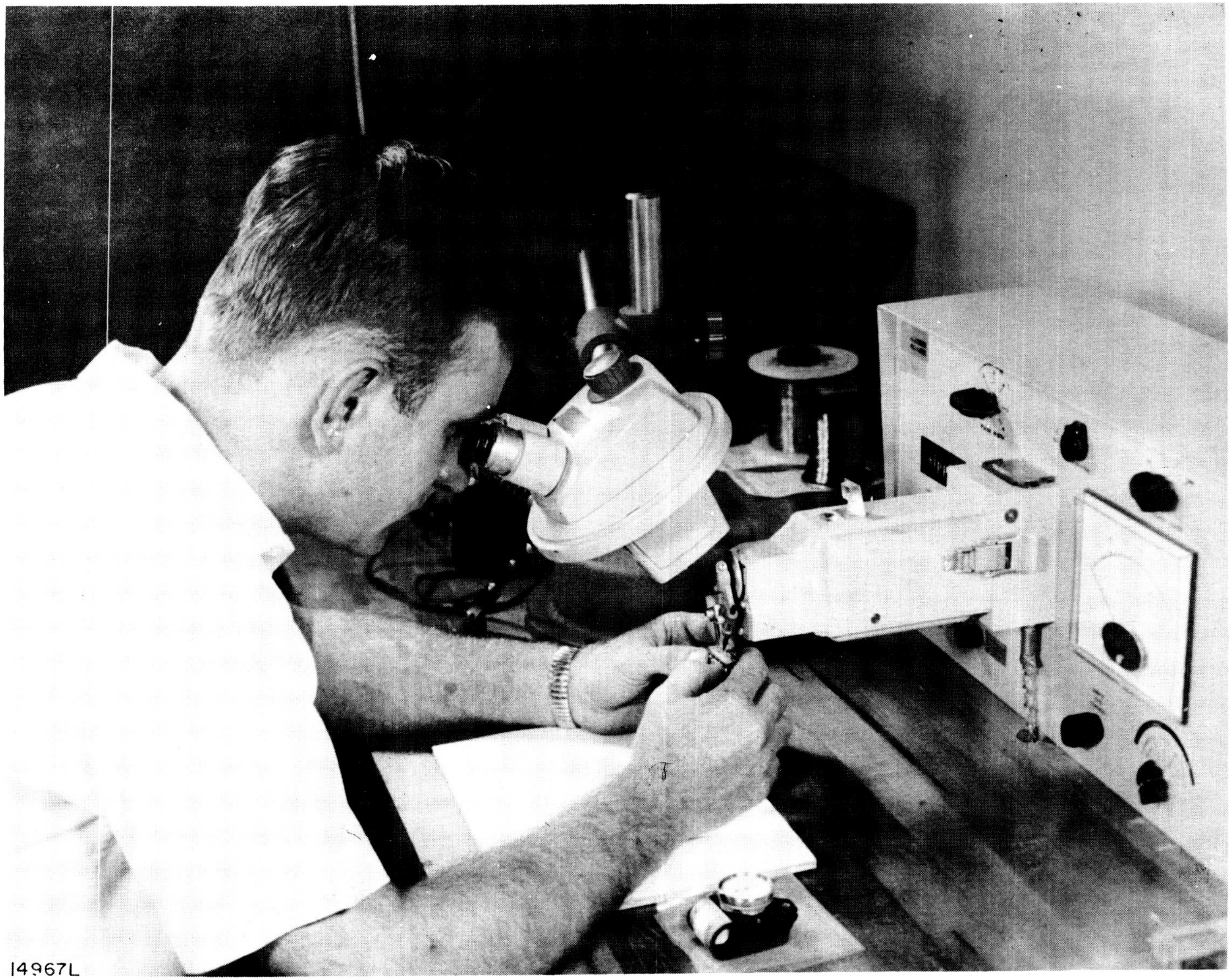

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Figure 19 WELDER FOR MODULE ASSEMBLY

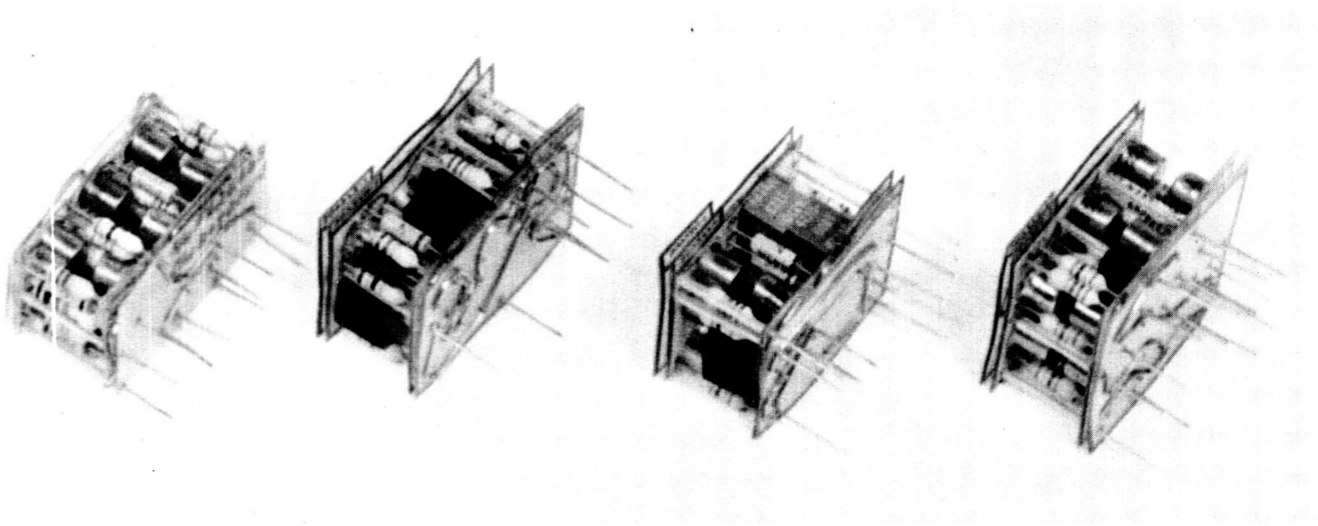

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Figure 20 WELDED MODULE ASSEMBLIES FOR THE POWER-AND SIGNAL-CONDITIONER PACKAGE

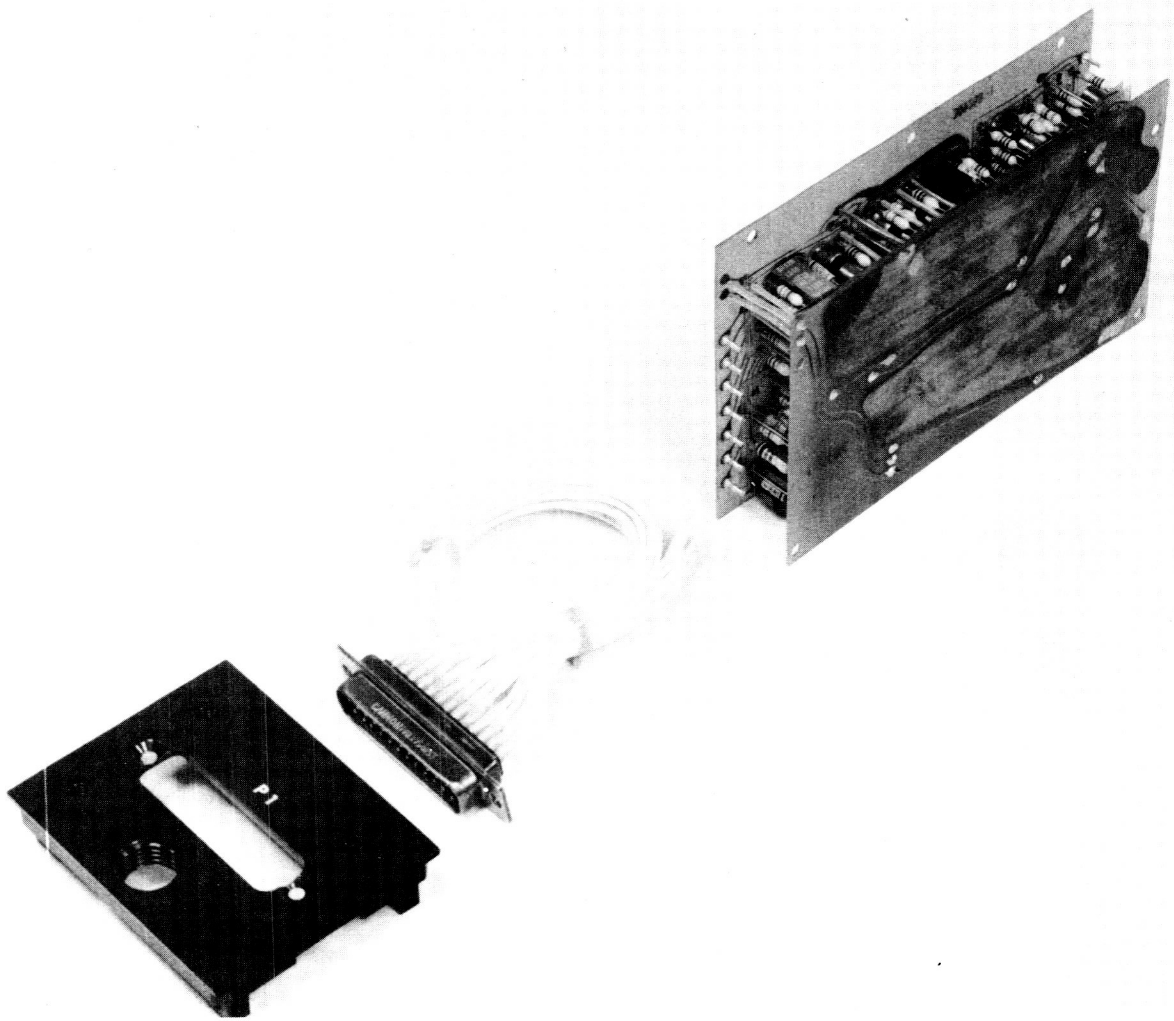

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Figure 21 PRINTED CIRCUIT ASSEMBLY FOR THE POWER-AND SIGNAL-CONDITIONER PACKAGE

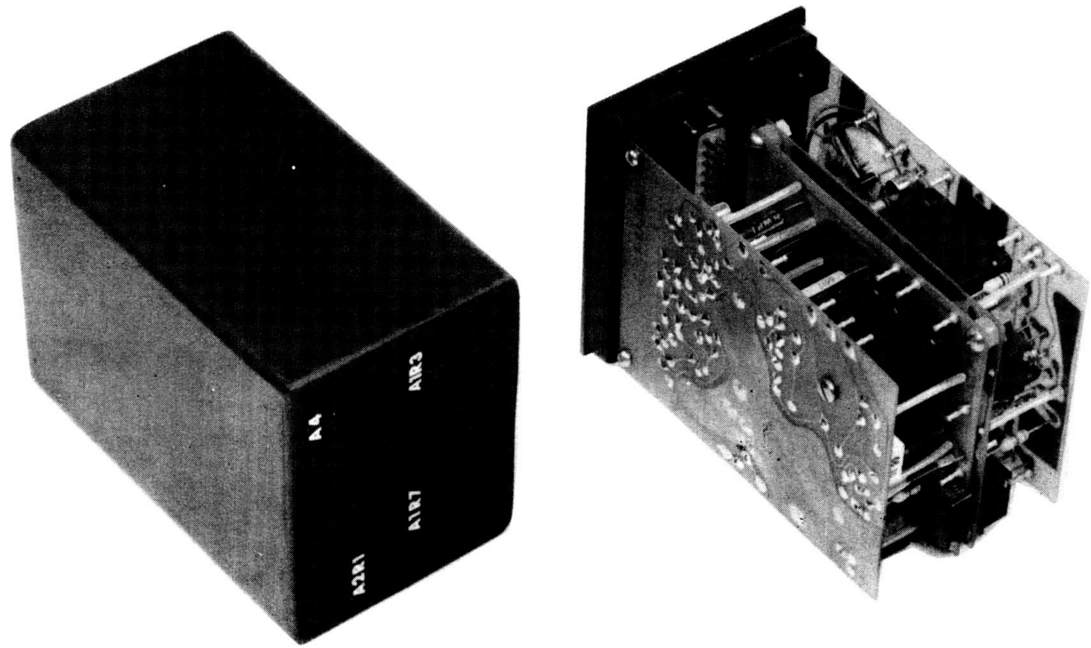

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Figure 22 PROPELLANT SUPPLY SIGNAL-CONDITIONER PACKAGE (ASSEMBLED)

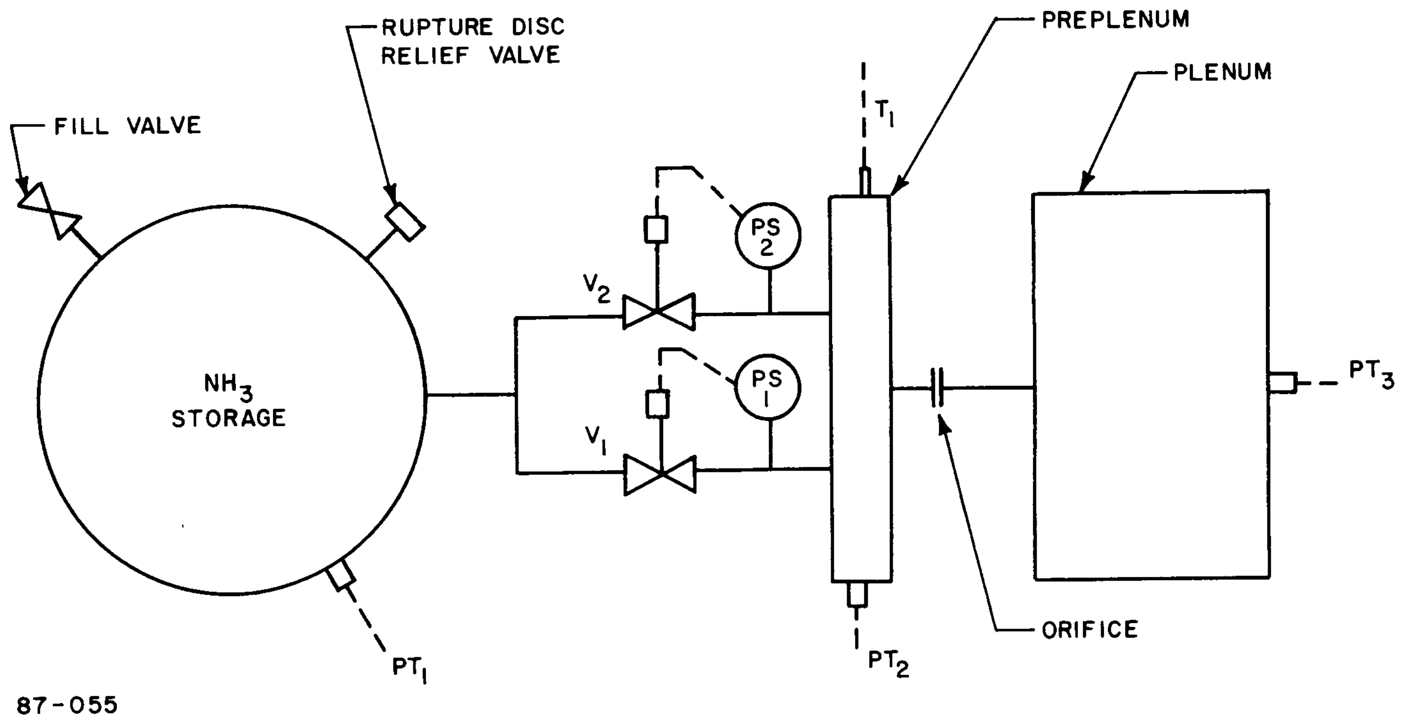

Figure 23 SCHEMATIC DIAGRAM OF THE ZERO-GRAVITY PROPELLANT FEED SYSTEM

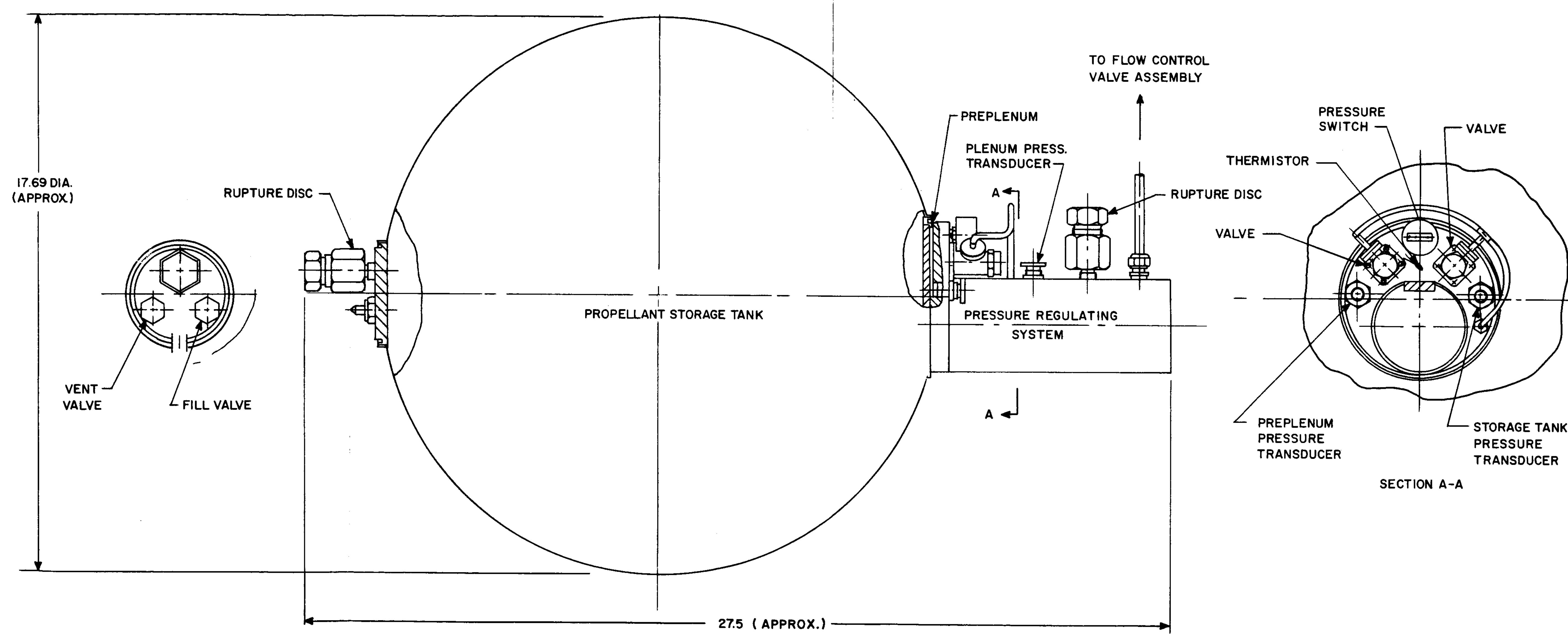

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Figure 24 ASSEMBLY DRAWING OF THE ZERO-GRAVITY PROPELLANT FEED SYSTEM

TABLE X

CRITICAL COMPONENTS IN THE ZERO-GRAVITY AMMONIA PROPELLANT FEED SYSTEM

Component	Manufacturer
Flow Control Valves, V_1 and V_2	Carleton Valve No. 1809-001-35
Pressure Switch, PS_1 and PS_2	Bristol Co. Pressure Switch No. C2069-1
Pressure Transducer, PT_2 and PT_3 (0 to 20 PSIA)	Micro Systems Pressure Transducer Model No. 1003-0151
Pressure Transducer PT_1 (0 to 300 PSIA)	Micro Systems Pressure Transducer Model No. 1003-0151

A critical problem in the development of the feed system has been to obtain reliable operation of valves, V_1, and V_2 when they are directly subject to liquid ammonia. When liquid ammonia is directly in contact with the neoprene valve seat material, the epoxy bond material between the stainless steel valve base and the seat tended to fail. This difficulty has been overcome by using a mechanical bond between the valve base and seat.

The basic components for the feed system have been completed and the system is undergoing evaluation.

E. THRUSTOR DESIGN AND EVALUATION

The basic resistojet thrustor design to be used in the three-axis system is the fast heat-up resistojet which has been described previously[1] and is shown in Figure 25. Briefly, the prototype engine consists of a solenoid valve (Carleton Valve No. 1809-001-35), a pressure transducer (Micro-Systems Model No. 1003-0151), and a combined fast heat-up heater and exit nozzle.

The original fast heat-up combination heater-exit nozzle was fabricated by vapor-deposition of the refractory heater material, e.g., tungsten, on a single material. Dimensional control of these heater elements was quite difficult. In the most recent designs, the heater and exit nozzle are fabricated separately and then electron-beam welded together at the nozzle entrance. The heater is made of vapor-deposited rhenium, and the exit nozzle is machined from a single piece of rhenium.

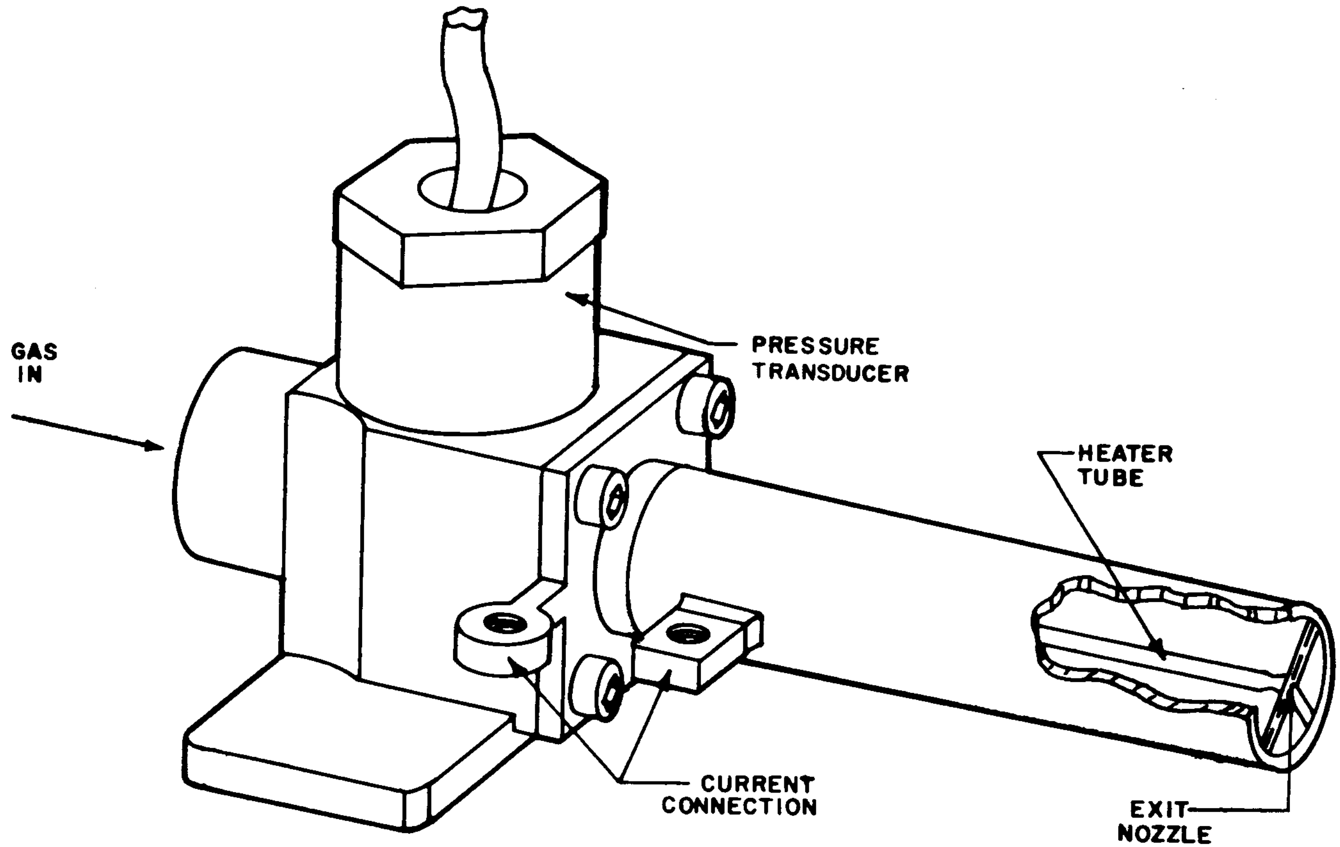

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Figure 25 SCHEMATIC DIAGRAM OF THE FAST HEAT-UP THRUSTOR ASSEMBLY

Typcial thrustor performance data, obtained on the single-axis wire table, is shown in Figure 26 and 27. Figure 26 presents thrust versus power input at a chamber pressure of 5 psia, and Figure 27 presents the specific impulse as a function of power input at the same conditions.

F. HARDWARE DELIVERY

As indicated previously, the three-axis resistojet system is being designed and developed using a modular subsystem concept for each axis. The basic hardware to be delivered is shown in Table XI.

TABLE XI

COMPONENTS TO BE DELIVERED TO NASA/LEWIS FOR THE THREE-AXIS RESISTOJET SYSTEM

I. Electronic	
Control Logic Packages	6
Power-and Signal-Conditioning Packages	6
Propellant-Conditioning Packages	2
Station-Keeping Packages	4
Adjustment Boxes	4
Junction Boxes	6
Commutator	1
Sensor and Light Source	1
II. Mechanical	
Propellant Storage and Feed System	2
Thrustor Assemblies	30
Thrustor Solenoid Valves	20
Thrustor Pressure Transducers	20

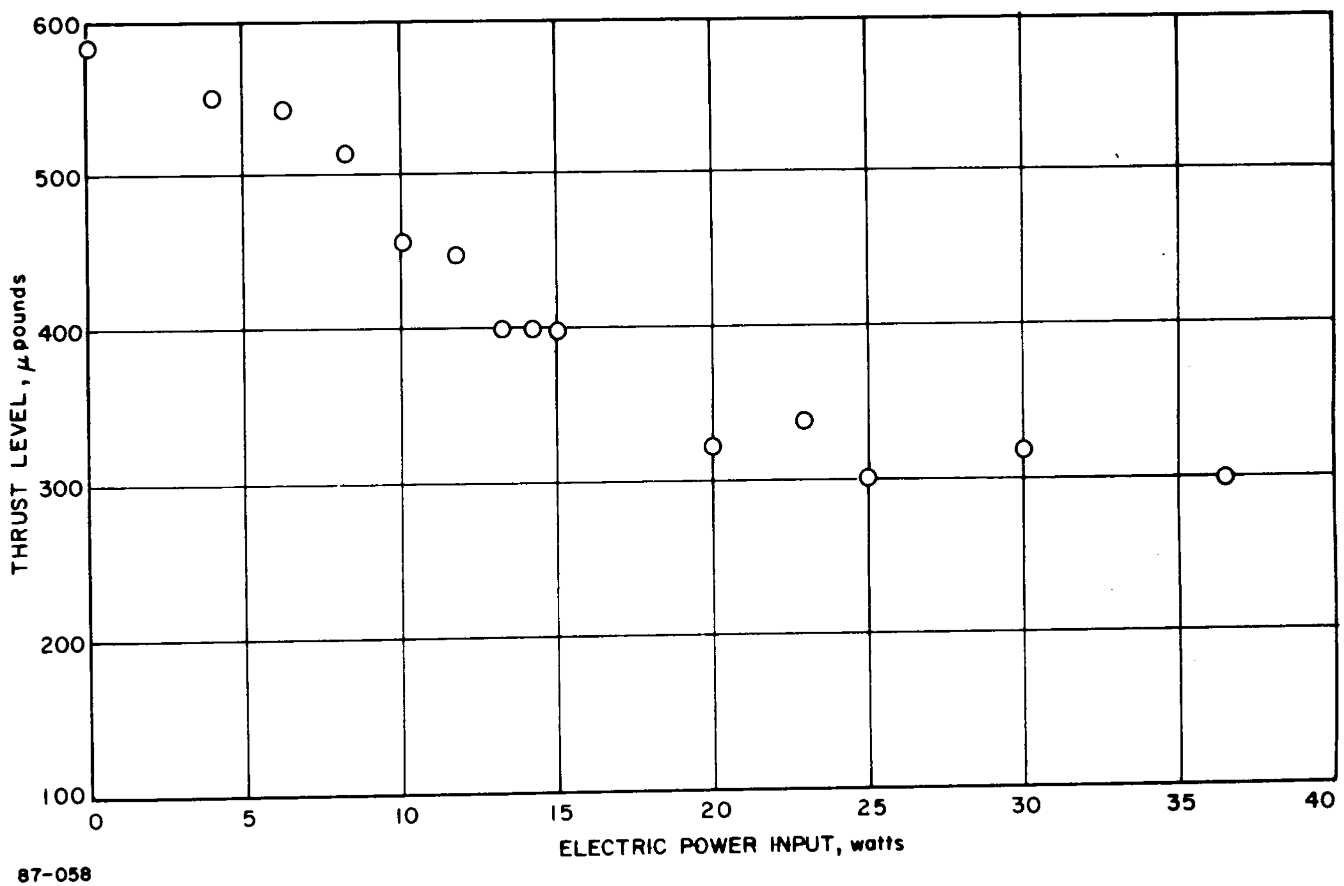

Figure 26 THRUST VERSUS ELECTRIC INPUT POWER FOR THE FAST HEAT-UP THRUSTOR

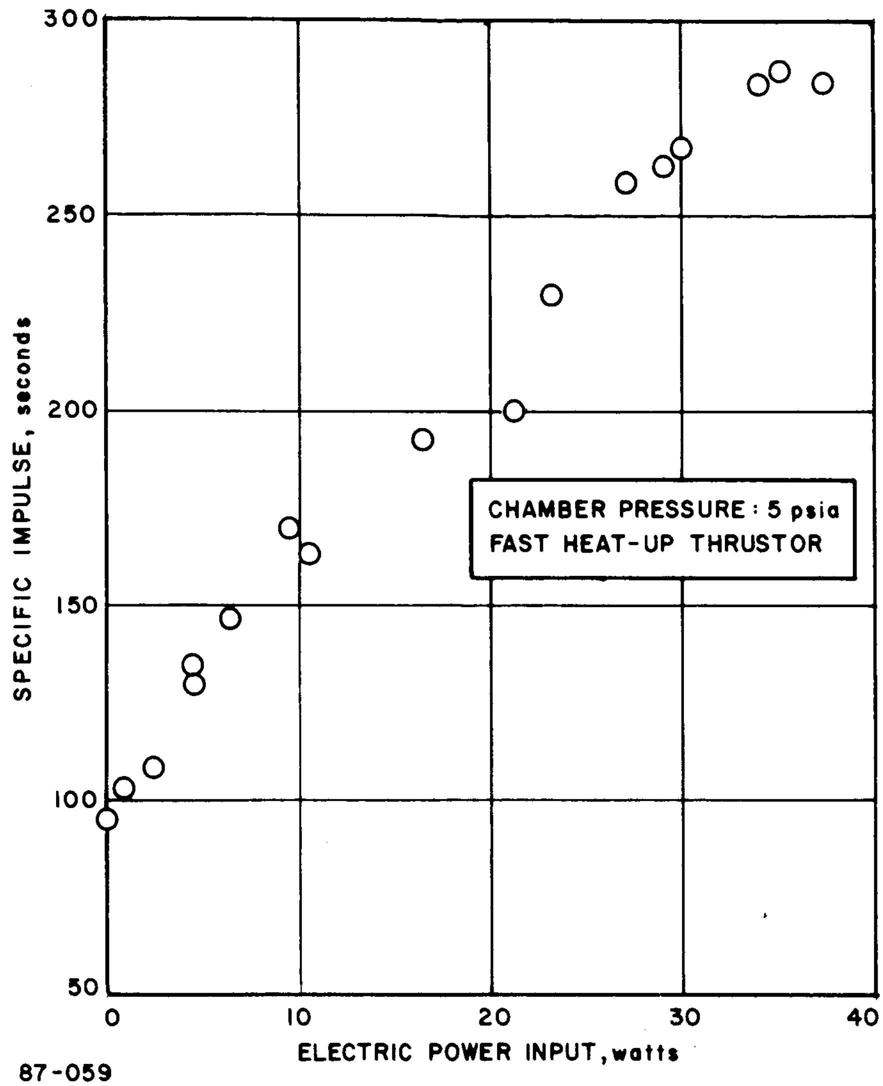

Figure 27 SPECIFIC IMPULSE VERSUS ELECTRIC INPUT POWER FOR THE FAST HEAT-UP THRUSTOR

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III. DIRECTION FOR FUTURE RESEARCH AND DEVELOPMENT

1. The deliverable hardware will be completed and tested in accordance with the specifications indicated in Appendix A through Appendix D.

2. A complete flight-quality, single-axis system will be evaluated on the wire table.

3. Each assembled thrustor unit will be subjected to the following tests:

   a. For thrust durations ranging from the minimum of system capability to 30 seconds, measurements will be made of total impulse, average specific impulse, mass flow rate, average thrustor current and voltage, and average thrustor power consumption.

   b. The average power, current, and voltage required for each valve will be measured.

   c. Measurements will be made of the average power and voltage for the propellant feed system under station-keeping, attitude control, and standby conditions.

   d. Calibration curves will be supplied for all instrumentation readout signals.

APPENDIX A

MODEL SPECIFICATIONS FOR LOGIC MODULE, MOD III

APPENDIX A

MODEL SPECIFICATIONS FOR LOGIC MODULE, MOD III

1. SCOPE.- This specification covers one type of equipment designated as Logic Module, Mod III. The Mod III Logic Module accepts an analog type signal from an attitude sensor and provides separate thrust-on and thrust-off signals in digital form to a power and signal conditioner.

2. APPLICABLE DOCUMENTS

2.1 Government documents.- The following Government documents of the issues in effect on the date of this specification form a part of this specification to the extent specified herein.

SPECIFICATIONS

Federal

PPP-B-566	Boxes, Folding, Paperboard
PPP-B-601	Boxes, Wood, Cleated Plywood
PPP-B-621	Boxes, Wood, Nailed and Lock Corner
PPP-B-636	Boxes, Fiberboard
PPP-C-843	Cushioning Material, Cellulosic

Military

MIL-MIL-P-116	Preservation, Methods of
MIL-C-45662	Calibration of Standards

STANDARDS

Military

MIL-STD-129	Marking for Shipment and Storage
MIL-STD-130	Identification Marking of U.S. Military Property
MIL-STD-810	Environmental Test Methods for Aerospace and Ground Equipment

(Copies of documents required by contractors in connections with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.1 Non-Government documents.- The following Non-Government documents of the issues in effect on the date of this specification form a part of this specification to the extent specified herein.

AVCO-Space Systems Division

DRAWING

309214 Logic Module, ATS-IV

(Application for copies should be addressed to AVCO Corporation, Space Systems Division, Lowell Industrial Park, Lowell, Massachusetts, 01851.)

3. REQUIREMENTS

3.1 Design qualification.- This specification makes provisions for qualification testing.

3.2 Design and construction.- The design and construction of the Logic Module, Part Number 309214-1, shall be in accordance with Drawing 309214.

3.3 Performance

3.3.1 Power requirement.- The Logic Module shall operate on a current not exceeding 75 milliamperes from a direct current (dc) source of 28.0 plus or minus 2.8 volts, as applied through terminals P1-18 (positive) and terminals P1-5 and P1-7 (negative).

3.3.2 Input signal.- The Logic Module shall accept dc input signals from 0 to plus or minus 1 volt through terminals P1-19 (positive) and P1-20 (negative ground), except that the input amplifier may saturate at not less than plus or minus 0.3 volt at zero rate, as indicated at output terminals P1-21 (positive) and P1-7 (negative) by leveling off of gain.

3.3.3 Position output (Telemetry (TLM)).- The transfer function from input terminals P1-19 (positive) and P1-20 (negative) to output terminals P1-16 (positive) and P1-7 (negative) shall satisfy the following equation within the range represented by the expression:

$$0.5 \text{ vdc} \leq V_{out} \leq 4.8 \text{ vdc}$$

Additionally, the output signal shall not exceed plus 5.25 volts dc nor be lower than minus 0.6 volt dc for any input.

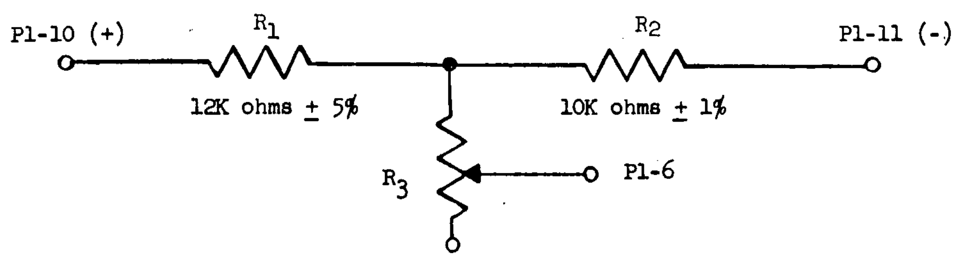
$$V_{out} = (2.5V + 14.0\ V_{in}) \pm 0.05V$$

3.3.4 Trigger circuit

3.3.4.1 Trigger level and "Execute" signal.- The Logic Module shall trigger when plus or minus 0.071 plus or minus 0.004 volts dc at zero rate is applied to terminals P1-19 (positive) and P1-20 (negative). Triggering shall be indicated by a change from 0.0 to plus 5.0 plus or minus 0.5 volts dc across a 1000 plus or minus 50-ohm load between "Execute" signal terminals P1-8 (positive) and P1-7 (negative). The 5.0 plus or minus 0.5 volt dc output signal shall be delivered across the "Execute" terminals for any input from the trigger voltage specified above to plus or minus 1 volt dc, and the rise time of the output signal shall be 500 microseconds.

3.3.4.2 Hysteresis.- The hysteresis of the trigger circuit shall vary from less than 5 percent to more than 40 percent when the resistance of R_3 of Figure 1 is varied from 60,000 to 0 ohms.

FIGURE 1



3.3.5 Transfer function (position plus rate).- With a sine wave input below the amplifier saturation level applied to terminals P1-19 (positive) and P1-20 (negative), the gain to output terminals P1-21 (positive) and P1-7 (negative) shall be as specified in Column 2 of Table I when terminals P1-22 and P1-14 are short circuited and terminal P1-23 is unconnected. With terminals P1-23 and P1-14 short circuited and terminal P1-22 open, the gain shall be as specified in Column 3 of Table I.

3.3.6 Polarity detector output.- The Logic Module shall indicate the polarity of the input signal as specified in 3.3.6.1 for negative signals and in 3.3.6.2 for positive signals. When the output signal changes state, the rise time of the output pulse shall be less than 500 microseconds. Each input signal shall be applied to terminals P1-19 (positive) and P1-20 (negative) and the output terminals shall be loaded with 1000 plus or minus 50 ohms between P1-9 and P1-7 and between P1-12 and P1-7. In the input signal region where -0.02 vdc $\leq V_{in} \leq$ +0.02 vdc, the output signal polarity shall be undefined and may be either of the following:

a. 5.0 plus or minus 0.5 volts dc across the output load between P1-9 (positive) and P1-7 (negative).

b. 5.0 plus or minus 0.5 volts dc across the output load between P1-12 (positive) and P1-7 (negative).

3.3.6.1 Clockwise signal out (negative input signal).- The Logic Module shall indicate an input signal in the range where -0.02 vdc $\leq V_{in} \leq$ -1.00 vdc by a plus 5.0 plus or minus 0.5 volt signal across the load between terminals P1-9 (positive) and P1-7 (negative).

3.3.6.2 Counterclockwise Signal out (positive input signal).- The Logic Module shall indicate an input signal in the range where +0.02 vdc $\leq V_{in} \leq$ + 1.00 vdc by a plus 5.0 plus or minus 0.5 volt signal across the load between terminals P1-12 (positive) and P1-7 (negative).

TABLE I

TRANSFER FUNCTION (POSITION PLUS RATE)

Column 1	Column 2 P1-22 connected to P1-14		Column 3 P1-23 connected to P1-14	
Frequency (cps)	Gain	Phase Angle (Ref. only)	Gain	Phase Angle (Ref. only)
0.05	34 ± 2 db	+28° ± 10%	34 ± 2 db	+3° ± 10%
0.1	37	+43°	37	+48°
0.2	42	+54°	42	+64°
0.4	47	+52°	48	+70°
0.7	51	+43°	53	+68°
1	52	+34°	55	+64°
2	54	+20°	59	+59°
3	54	+13.5°	61	+37.5°
5	54	+8°	62	+25°
7	54	+6°	63	+19°
10	54	+4.5°	63	+14°
20	54	+2°	63	+7°
50	54 ± 2 db	+1° ± 10%	63 ± 2 db	+3° ± 10%

3.3.7 Position plus rate monitor (TLM).- With an input signal applied between P1-19 (positive) and P1-20 (negative), the transfer function from terminals P1-21 (positive) and P1-7 (negative) to output terminals P1-13 (positive) and P1-7 (negative) shall satisfy the equation:

$$V_{out} = (2.5 \text{ vdc} - 0.302 V_{in}) \pm 0.05 \text{ vdc}$$

for inputs in the range of plus 0.5 vdc $\leq V_{out} \leq$ plus 4.8 vdc, except that for any input, the output signal shall not exceed plus 5.25 volts dc nor be lower than minus 0.6 volts dc.

3.3.8 Battery current (TLM).- With 28.0 plus or minus 2.8 volts dc supplied through input terminals P1-18 (positive) and P1-5 and P1-7 (negative), the output voltage across terminals P1-17 (positive) and P1-7 (negative) shall satisfy the equation

$$I_{supply} = (0.44 V_{out} \pm 0.1) \text{ Amperes}$$

for inputs in the range of plus 0.5 vdc $\leq V_{out} \leq$ plus 4.8 vdc, except that for any input, the output signal shall not exceed plus 5.25 volts dc nor be lower than 0.6 volts dc.

3.4 Environments

3.4.1 Non-operating.- The Logic Module shall meet the requirements of 3.2 and 3.3 after exposure to the following non-operating environmental conditions.

a. Temperature (transportation, handling, and storage).- Minus 22 plus or minus 4 degrees Fahrenheit (F) to plus 140 plus or minus 4 degrees F.

b. Shock.- Exposure to a 35g triangular shock pulse of 10 milliseconds (ms) in each direction along each of 3 mutually perpendicular axes.

c. Vibration (sinusoidal).- Exposure to sinusoidal vibration as specified in Table II along the axes shown.

TABLE II

SINUSOIDAL VIBRATION

* At a sweep rate of 1.0 octave per minute.

Vibratory Acceleration Zero to Peak g*	Frequency Range (cps)	Axis
± 4.0	10 to 50	Thrust (Z-Z)
± 9.0	50 to 250	
± 15.0	250 to 400	
± 30.0	400 to 2000	
± 3.0	10 to 50	Lateral (X-X and Y-Y)
± 6.0	50 to 250	
± 12.0	250 to 400	
± 24.0	400 to 2000	

d. Vibration (random noise).- Exposure along each of 3 mutually perpendicular axes to Gaussian random vibration as specified in Table III, with g-peaks clipped at 3 times the root-mean-square (rms) acceleration.

TABLE III

RANDOM NOISE VIBRATION

Power Spectral Density (g^2/cps)	Acceleration (g rms)	Frequency Range (cps)	Duration (minutes per axis)
0.145	6.0	20 to 250	4
0.32	24.0	250 to 2000*	4

* Roll off at 40 db/octave above 2000 cps.

3.4.2 Operating.- The Logic Module shall meet the requirements of 3.2 and 3.3 during and after exposure to the following operating environmental conditions.

a. Thermal-vacuum.- With the Logic Module in a vacuum of less than 10^{-3} Torr, exposure of one side of the module for 6 hours to solar radiation at 1 astronomical unit (AU) (135 watts per square foot) while operating for a minimum duty cycle of 15 percent with an "operating" time of not less than 2 seconds.

3.5 Weight.- The weight of the Logic Module shall be pounds.

3.6 Identification.- The Logic Module shall be marked for identification in accordance with MIL-STD-130.

3.7 Workmanship.- The Logic Module shall be fabricated and finished in such a manner that the criteria of appearance, fit, and adherence to specific tolerances shall be observed. Particular attention shall be given to the neatness and thoroughness of soldering, welding, wiring, potting, marking, plating, machine screw assemblage, freedom of parts from burrs and sharp edges, and freedom of cables from cracks and cuts.

4. QUALITY ASSURANCE PROVISIONS

4.1 Classification of tests. - The inspection and testing of the Logic Module shall be classified as follows:

a. Acceptance tests (see 4.2).

b. Qualification tests (see 4.5).

c. Preservation, packaging, and packing tests (see 4.6).

4.2 Acceptance Tests. - Each Logic Module shall be subjected to the tests of Table IV in the sequence shown.

TABLE IV

INDIVIDUAL TESTS

Sequence	Test	Test Method Reference
1	Examination of product	4.4.1
2	Performance Tests	4.4.2
3	Weight	4.4.4
4	Identification	4.4.5
5	Workmanship	4.4.6

4.3 Test Conditions and Tolerances

4.3.1 Atmospheric conditions.- Unless otherwise specified, all tests required by this specification shall be made at an atmospheric pressure of 28 to 32 inches of mercury, a temperature of 60 to 95 degrees F, and a relative humidity of 90 percent or less.

4.3.2 Measurements. - All measurements shall be made with instruments whose accuracy has been verified in accordance with Specification MIL-C-45662.

4.3.3 Test Tolerances. - Unless otherwise specified, the tolerances of all test parameters of 4.4 shall be as follows:

a. Temperature. - Under plus 100 degrees F, plus or minus 4 degrees F. Over plus 100 degrees F, plus or minus 4 percent.

b. Pressure . - Plus or minus 5 percent.

c. Vibration amplitude

(1) Random. - Plus or minus 3 decibels.

(2) Sinusoidal. - Plus or minus 10 percent.

d. Vibration frequency. - Plus or minus 2 percent.

e. Shock. - Plus or minus 10 percent.

4.3.4 Temperature source. - Unless otherwise specified, the temperature source of the test facilities shall be so located that no portion of the Logic Module will be subjected to the direct temperature source during either the temperature tests or the temperature varying portions of test cycles.

4.3.5 Protective caps. - During the environmental tests, the connectors shall have protective caps properly installed in accordance with Drawing 309214 or shall be engaged with mating connectors.

> CAUTION
>
> Protective caps shall be used only on the specific Logic Module with which they are delivered and shall not be used again.

4.4 Test Methods. - The following test methods shall be used to verify conformance to the requirements of this specification.

4.4.1 Examination of product. - Examine each Logic Module for conformance to Drawing 309214 (reference 3.2).

4.4.2 Performance Tests

4.4.2.1 Power requirement. - Apply 30.8 volts d.c. between the terminals specified in 3.3.1. Measure the current for conformance to 3.3.1.

4.4.2.2 Input signal. - Energize the module as specified in 4.4.2.1. Apply input signal to the terminals specified in 3.3.2. Vary the magnitude of the input signal linearly from 0 to 1.0 volt in the positive and negative direction at a rate of 0.01 cycle per second (test equivalent for zero rate). Measure the output voltage and check for amplifier saturation. Check for conformance to 3.3.2. If the saturation requirement is not attained,repeat with input signals of higher rate and check for conformance to 3.3.2.

4.4.2.3 Position output (TLM). - Energize the Module as specified in 4.4.2.1. Apply input signals of the levels specified in paragraph 3.3.2 to the specified terminals. Measure the output voltage, and check the voltage transfer function for conformance to 3.3.3.

4.4.2.4 Trigger Circuit

4.4.2.4.1 Trigger level and "Execute" signal - Energize the module as specified in 4.4.2.1. Apply the specified input signal and resistive load between the terminals as stated in 3.3.4.1. Monitor the voltage at the output terminals to determine that the module triggers. Check the voltage and rise time for conformance to 3.3.4.1.

4.4.2.4.2 Hysteresis - Connect load resistors to the module as specified in 3.3.4.2. Energize the module with the voltage of 3.3.1, apply the input trigger signal of 3.3.4.1, and note the actual trigger voltage. Reduce the input signal and note the actual trigger-off level. Perform this test over the range of resistance specified in 3.3.4.2 and check the hysteresis for conformance to 3.3.4.2.

4.4.2.5 Transfer function (position plus rate)- Energize the module as specified in 4.4.2.1. Connect terminals as specified and apply a sinusoidal input signal in accordance with 3.3.5. Vary the frequency of the input signal as indicated in Table I and measure the output voltage magnitude and phase shift with a servo analyzer or other suitable device. Check the output voltage magnitude and phase shift (reference only) for conformance to 3.3.5.

4.4.2.6 Polarity detector output - Connect the resistance loads as specified in 3.3.6 and energize the module as specified in 4.4.2.1. Provide instrumentation for measuring the output voltage magnitude and rise time.

4.4.2.6.1 Clockwise signal out - Apply the minimum input signal of 3.3.6.1 and measure the output voltage for conformance to 3.3.6.1.

4.4.2.6.2 Counter-clockwise signal out - Apply the minimum input signal of 3.3.6.2 and measure the output voltage for conformance to 3.3.6.2.

4.4.2.7 Position plus rate monitor (TLM) - Energize the module as specified in 4.4.2.1. Apply input signals between the terminals specified in 3.3.7 and measure the input and output voltages. Calculate the output voltage from the transfer function given in 3.3.7. Check that the output voltage conforms to 3.3.7.

4.4.2.8 Battery current (TLM) - Energize the module as specified in 4.4.2.1 and measure the supply current. Measure the output voltage between the terminals specified in 3.3.8 and calculate the supply current from the equation of 3.3.8. Check the supply current and output voltage for conformance to 3.3.8 for the range of 0 to 2 amperes input current.

4.4.3 Environmental tests

4.4.3.1 Non-operating tests - The Logic Module shall be subjected to the following non-operating environmental tests to verify conformance to 3.4.1.

4.4.3.1.1 Temperature (transportation, handling, and storage) - Subject the Logic Module to a temperature of minus 22 plus or minus 4 degrees F for 3 hours. Raise the temperature to standard (see 4.3.1) and maintain until the temperature of the Logic Module does not vary more than 2 degrees F within 15 minutes, then raise the temperature to 140 plus or minus 6 degrees F and stabilize the temperature of the Logic Module as specified above. Return the temperature to standard and maintain until the Logic Module temperature is stabilized as specified above. Perform the tests of 4.4.1, 4.4.2.1, 4.4.2.2, 4.4.2.3, and 4.4.2.4 (reference 3.4.1.a).

4.4.3.1.2 Shock.- Subject the Logic Module to a 35g triangular pulse of 10 milliseconds duration in accordance with Procedure V, method 516 shock test of Standard MIL-STD-810. Apply the shock through the normal mounting points or surfaces of the Logic Module one time in each direction along each of 3 mutually perpendicular axes. Perform the tests of 4.4.1, 4.4.2.1, 4.4.2.2, and 4.4.2.3. (Reference 3.4.1.b)

4.4.3.1.3 Vibration (sinusoidal).- Subject the Logic Module, through the normal mounting points or surfaces, to the sinusoidal vibration sweeps defined in Table II. Perform 1 sweep through each frequency range in each direction along the axis specified in the table at a sweep rate of 1.0 octave per minute. Perform the tests of 4.4.1, 4.4.2.1, 4.4.2.2, and 4.4.2.3. (Reference 3.4.1.c)

4.4.3.1.4 Vibration (random noise).- Subject the Logic Module, through the normal mounting points or surfaces, to the random vibration specified in 3.4.1.d and Table III. Apply vibration of each spectral density for the duration shown, once along each of 3 mutually perpendicular axes. Perform the tests of 4.4.1, 4.4.2.1, 4.4.2.2, and 4.4.2.3. (Reference 3.4.1.d)

4.4.3.2 Operating tests.- The Logic Module shall be subjected to the following operating environmental test to verify conformance to 3.4.2.

4.4.3.2.1 Thermal vacuum.- Subject the Logic Module to a vacuum of less than 10^{-3} Torr. While at this vacuum, subject one side of the Logic Module to a radiation of 1 astronomical unit (135 watts/ft^2) for a period of 6 hours. During this environment, perform the tests of 4.4.2.1, 4.4.2.2, 4.4.2.3, 4.4.2.4, 4.4.2.6, and 4.4.2.7.. After this environment, perform the tests of 4.4.1 and 4.4.2. (Reference 3.4.2.a)

4.4.4 Weight.- Weigh each Logic Module and check for conformance to 3.5.

4.4.5 Identification.- Examine each Logic Module for conformance to 3.6.

4.4.6 Workmanship.- Examine the Logic Module to make certain that the requirements of 3.7 are met.

4.5 Qualification testing

4.5.1 Qualification test samples.- The qualification test samples shall consist of specimens representative of the production equipment. They shall be tested at a laboratory designated by the procuring activity (see 6.3), or when so stated in the contract, at the contractor's plant under the supervision of the procuring activity.

4.5.2 Qualification tests.- Qualification tests shall include all tests specified under 4.4. Qualification testing shall be conducted only when and to the extent specified in the contract.

4.6 Preservation, packaging, and packing.- Inspection shall be sufficient to ensure that the requirements of Section 5 are met.

5. PREPARATION FOR DELIVERY

5.1 Preservation and packaging shall be Level A or C as specified by the procuring activity.

5.1.1 Level A.- Each Logic Module shall be packaged in accordance with Method IA-8 of MIL-P-116. The Logic Module shall be wrapped in cushioning material conforming to PPP-C-843 and placed in a container conforming to PPP-B-566 or PPP-B-636. The cushioning shall be packed so that no voids exist between the item and the container.

5.1.2 Level C - Each Logic Module shall be packaged in accordance with 5.1.1, except that it shall be packaged in accordance with Method III of MIL-P-116.

5.2 Packing.- Packing shall be Level A, B, or C as specified by the procuring activity.

5.2.1 Level A.- The Logic Module, packaged as specified in 5.1.1 or 5.1.2, shall be packed in containers conforming to Class 2 of PPP-B-636, Class 2 of PPP-B-621 or PPP-B-601 (overseas type.) Suitable dunnage shall be packed between unit packages and exterior container to prevent shifting of unit packages.

5.2.2 Levels B and C.- The Logic Module, packaged as specified in 5.1.1 or 5.1.2, shall be packed in containers conforming to Class 1 of PPP-B-636, Class 1 of PPP-B-621 or PPP-B-601 (domestic type.) Suitable dunnage shall be packed between unit packages and exterior container to prevent shifting of the unit packages.

5.3 Marking.- In addition to any special marking required by the contract or order, all interior and shipping containers shall be marked in accordance with MIL-STD-129.

6. NOTES

6.1 Intended use.- The Logic Module covered by this specification is intended for use as a control element in the ATS-IV resistojet thrustor system for three-axis attitude control and two direction station keeping of a stable platform type satellite.

6.2 Ordering data.- Procurement documents should specify the following:

a. The title, number and date of this specification.
b. Applicable stock number.
c. Serialization requirements.
d. The level of preservation, packaging and packing.
e. Whether design qualification tests are required, and the number of qualification test specimens to be submitted.

6.3 Procuring activity.- For the purposes of this specification, the procuring activity shall be defined as the National Aeronautics and Space Administration (NASA) or other Department of Defense activity responsible for the Mod III contract.

APPENDIX B

MODEL SPECIFICATIONS FOR POWER AND SIGNAL-CONDITIONING MODULE, MOD III

APPENDIX B

MODEL SPECIFICATIONS FOR POWER

AND SIGNAL-CONDITIONING MODULE,

MOD III

1. SCOPE.- This specification covers one type of equipment designated as the Power and Signal Conditioning Module, Mod III. The Mod III Power and Signal Conditioning Module (hereinafter referred to as the P & S Conditioner) accepts logic signals and telemetry commands and processes them to deliver optimum clockwise and counterclockwise power outputs to corresponding external resistive loads and flow control valves. Additionally, the P & S Conditioner accepts pressure sensor signals and provides voltage limited outputs; also, provides a source of constant power for transducers and supplies monitoring output voltages proportional to flow valve voltages, heater voltages, heater current, and gas pressures.

2. APPLICABLE DOCUMENTS

2.1 Government documents.- The following Government documents of the issues in effect on the date of this specification form a part of this specification to the extent specified herein.

SPECIFICATIONS

Federal

PPP-B-566	Boxes, Folding, Paperboard
PPP-B-601	Boxes, Wood, Cleated-Plywood
PPP-B-621	Boxes, Wood, Nailed and Lock-Corner
PPP-B-636	Boxes, Fiberboard
PPP-B-676	Boxes, Set-Up, Paperboard
PPP-C-843	Cushioning Material, Cellulosic

Military

MIL-P-116	Preservation, Methods of
MIL-C-45662	Calibration of Standards

STANDARDS

Military

MIL-STD-129	Marking for Shipment and Storage
MIL-STD-130	Identification Marking of U.S. Military Property
MIL-STD-810	Environmental Test Methods for Aerospace and Ground Equipment

(Copies of documents required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 Non-Government documents.- The following non-Government documents of the issues in effect on the date of this specification form a part of this specification to the extent specified herein.

2.2.1 Avco-Space Systems Division

DRAWING

309180	Power and Signal Conditioning Module, ATS-IV

(Application for copies should be addressed to Avco Corporation, Space Systems Division, Lowell Industrial Park, Lowell, Massachusetts, 01851.)

2.2.2 Uniform Freight Classification Committee

HANDBOOK

Uniform Freight Classification Rules

(Application for copies should be addressed to Uniform Freight Classification Committee, 202 Chicago Union Station, Chicago 6, Illinois.)

3. REQUIREMENTS

3.1 Design qualification.- This specification makes provisions for qualification testing.

3.2 Design and construction.- The design and construction of the Power and Signal Conditioning Module, Part Number 309180-1, shall be in accordance with Drawing 309180.

3.3 Performance

3.3.1 Power requirement.- The P & S Conditioner shall operate on a current not exceeding 600 milliamperes from a direct current (dc) source of 28.0 plus or minus 2.8 volts, applied through terminals J1-15, J1-26, and J1-27 (positive) and J1-3, J1-28, and J1-21 (negative).

3.3.2 Operation.- The P & S Conditioner shall have the following modes of operation:

a. Automatic (see 3.3.2.1 and 3.3.2.2).

b. Manual (see 3.3.2.3 and 3.3.2.4).

c. Hot gas (see 3.3.2.1 through 3.3.2.4).

d. Cold gas (see 3.3.2.5 and 3.3.2.6).

The P & S Conditioner always shall be in the automatic and hot gas modes upon initial power application in accordance with 3.3.1, and thereafter shall operate as specified in the following subparagraphs. See 6.3 hereof for definitions of input and output nomenclature.

3.3.2.1 Automatic mode, clockwise input signal.- With the P & S Conditioner operating in the automatic mode (see 3.3.2), application of a 5.0 plus or minus 0.5 volt dc signal to clockwise (CW) input terminals J1-30 (positive) and J1-21 (negative) and a 5.0 plus or minus 0.5 volt dc signal to "execute" input terminals J1-31 (positive) and J1-21 (negative) shall result, within 500 microseconds after application of the "execute" signal, in an alternating current (ac) pulse width modulated square wave power output of 7.5 plus or minus 0.3 watts into a 0.100 plus or minus 0.001 ohm resistive load across CW heater power output terminals E-1 and E-2. Additionally, at 1.00 plus or minus 0.15 seconds after application of the "execute" signal, 28.0 plus or minus 2.8 volts dc shall be delivered across a 240 plus or minus 48 ohm resistive load connected to CW valve power output terminals J1-24 (positive) and J1-21 (negative). The outputs shall return to zero within 10 milliseconds after removal of either or both input signals.

3.3.2.2 Automatic mode, counterclockwise input signal.- With the P & S Conditioner in the automatic mode, application of a 5.0 plus or minus 0.5 volt dc signal to counterclockwise (CCW) input terminals J1-32 (positive) and J1-21 (negative) and a 5.0 plus or minus 0.5 volt dc signal to "execute" input terminals J1-31 (positive) and J1-21 (negative) shall result, within 500 microseconds after application of the "execute" signal, in an ac pulse width modulated square wave power output of 7.5 plus or minus 0.3 watts into a 0.100 plus or minus 0.001 ohm resistive load across CCW heater power output terminals E-3 and E-4. Additionally, at 1.00 plus or minus 0.15 seconds after application of the "execute" signal, 28.0 plus or minus 2.8 volts dc shall be delivered across a 240 plus or minus 48 ohm resistive load connected to CCW valve power output terminals J1-33 (positive) and J1-21 (negative). The outputs shall return to zero within 10 milliseconds after removal of either or both input signals.

3.3.2.3 Manual mode, clockwise slew command.- With the P & S Conditioner in the automatic mode and 5.0 plus or minus 0.5 volt dc signals applied to the CCW and "execute" input terminals in conformance to 3.3.2.2, the application of a slew command dc pulse of 5.0 plus or minus 0.5 volts for at least 10 milliseconds to CW manual command input terminals J1-25 (positive) and J1-21 (negative) shall de-energize the CCW outputs of 3.3.2.2 and energize the CW outputs in accordance with 3.3.2.1, except that the valve power voltage shall be delivered with zero time delay. Application of a second identical pulse to the CW manual command input terminals shall de-energize the CW outputs within 10 milliseconds, after which the application of a 5.0 plus or minus 0.5 volt dc pulse for not less than 10 milliseconds to automatic mode command input terminals J1-26 (positive) and J1-21 (negative) shall energize the CCW outputs in the automatic mode in conformance to 3.3.2.2.

3.3.2.4 Manual mode, counterclockwise slew command.- With the P & S Conditioner in the automatic mode and 5.0 plus 0.5 volt dc signals applied to the CW and "execute" input terminals in conformance to 3.3.2.1, the application of a slew command dc pulse of 5.0 plus or minus 0.5 volts for at least 10 milliseconds to CCW manual command input terminals J1-27 (positive) and J1-21 (negative) shall de-energize the CW outputs of 3.3.2.1 and energize the CCW outputs in accordance with 3.3.2.2, except that the valve power voltage shall be delivered with zero time delay. Application of a second identical pulse to the CCW manual command input terminals shall de-energize the CCW outputs within 10 milliseconds, after which the application of a 5.0 plus or minus 0.5 volt dc pulse for not less than 10 milliseconds to automatic command input terminals J1-26 (positive) and J1-21 (negative) shall energize the CW outputs in the automatic mode in conformance to 3.3.2.1.

3.3.2.5 Hot-to-cold gas mode command, clockwise.- With the P & S Conditioner in either the automatic or the manual mode and delivering power to the CW loads in conformance to 3.3.2.1 or 3.3.2.3 respectively, application of a hot-to-cold gas mode command dc pulse of 5.0 plus or minus 0.5 volts for at least 10 milliseconds to hot/cold gas command input terminals J1-34 (positive) and J1-21 (negative) shall cancel the 7.5 watt output into the CW heater power output load within 10 milliseconds.

3.3.2.6 Hot-to-cold gas mode command, counterclockwise.- With the P & S Conditioner in either the automatic or the manual mode and delivering power to the CCW loads in conformance to 3.3.2.2 or 3.3.2.4 respectively, application of a hot-to-cold gas mode command dc pulse of 5.0 plus or minus 0.5 volts for at least 10 milliseconds to hot/cold gas command input terminals J1-34 (positive) and J1-21 (negative) shall cancel the 7.5 watt output into the CCW heater power output load within 10 milliseconds.

3.3.2.7 Nozzle box pressure transducer power, clockwise and counterclockwise.- With the P & S Conditioner operating in conformance to 3.3.1, in any combination of the modes of 3.3.2, 15.00 plus or minus 0.75 milliamperes dc shall be furnished into variable 400-to-700-ohm loads connected across CW pressure transducer power output terminals J1-4 (positive) and J1-7 (negative) and across CCW pressure transducer power output terminals J1-13 (positive) and J1-9 (negative).

3.3.3 Signals.- The P & S Conditioner shall provide the signals specified in the following subparagraphs.

3.3.3.1 Valve power output, clockwise.- When the P & S Conditioner is supplying CW valve power in conformance to 3.3.2.1, 3.3.2.3,or 3.3.2.5, a 2.55 plus or minus 0.25 volt dc signal shall be furnished at CW valve signal output terminals J1-2 (positive) and J1-21 (negative). Zero volts across these terminals shall indicate that CW valve power output is de-energized (off).

3.3.3.2 Valve power output, counterclockwise.- When the P & S Conditioner is supplying CCW valve power in conformance to 3.3.2.2, 3.3.2.4,or 3.3.2.6, a 2.55 plus or minus 0.25 volt dc signal shall be furnished at CCW valve signal output terminals J1-23 (positive) and J1-21 (negative). Zero volts across these terminals shall indicate that CCW valve power is off.

3.3.3.3 Heater power output, clockwise.- When the P & S Conditioner is supplying CW heater power in conformance to 3.3.2.1 or 3.3.2.3, a 3.90 plus or minus 0.25 volt dc analog signal shall be furnished at CW heater voltage signal output terminals J1-35 (positive) and J1-21 (negative), and a 2.70 plus or minus 0.25 volt dc analog signal shall be furnished at heater current signal output terminals J1-36 (positive) and J1-21 (negative). Zero volts across these two sets of terminals shall indicate that CW heater voltage and current are off.

3.3.3.4 Heater power output, counterclockwise.- When the P & S Conditioner is supplying CCW heater power in conformance to 3.3.2.2 or 3.3.2.4, a 3.90 plus or minus 0.25 volt dc analog signal shall be furnished at CCW heater voltage signal output terminals J1-37 (positive) and J1-21 (negative), and a 2.70 plus or minus 0.25 volt dc analog signal shall be furnished at heater current signal output terminals J1-36 (positive) and J1-21 (negative). Zero volts across these two sets of terminals shall indicate that CCW heater voltage and current are off.

3.3.3.5 Nozzle box pressure, clockwise.- With the P & S Conditioner operating in conformance to 3.3.2.7, differential dc input signals in the range of 0 to 50 millivolts applied to CW nozzle box presssure sensor input terminals J1-10 (positive) and J1-11 (negative) shall result in dc analog output signals at CW pressure signal output terminals, J1-12 (positive) and J1-21 (negative. The magnitude of the nozzle box pressure signals shall satisfy the following equation:

$$V_{out} = 100 \pm 2\% \; V_{in} \pm 20 \text{ millivolts (mv)}$$
$$= \left[(98 \text{ to } 102) \; V_{in} \right] \pm 20 \text{ mv.}$$

3.3.3.6 Nozzle box pressure, counterclockwise.- With the P & S Conditioner operating in conformance to 3.3.2.7, differential dc input signals in the range of 0 to 50 millivolts applied to CCW nozzle box pressure sensor input terminals J1-5 (positive) and J1-8 (negative) shall result in dc analog nozzle box pressure output signals satisfying the equation of 3.3.3.5 at CCW pressure signal output terminals J1-6 (positive) and J1-21 (negative).

3.4 Environments

3.4.1 Nonoperating.- The P & S Conditioner shall meet the requirements of 3.2 and 3.3 after exposure to the following nonoperating environmental conditions:

a. Temperature (transportation, handling, and storage).- Minus 22 plus or minus 4 degrees Fahrenheit (F) to plus 140 plus or minus 4 degrees F.

b. Shock.- Exposure to 35g triangular shock pulse of 10 milliseconds duration along each of 3 mutually perpendicular axes.

c. Vibration (sinusoidal).- Exposure to sinusoidal vibration as specified in Table I along the axes shown.

d. Vibration (random noise).- Exposure along each of 3 mutually perpendicular axes to Gaussian random vibration as specified in Table II, with g-peaks clipped at 3 times the root-mean-square (rms) acceleration.

TABLE I

SINUSOIDAL VIBRATION

Vibratory Acceleration Zero to Peak g*	Frequency Range (cps)	Axis
0.4 inch double amplitude ± 4.0 ± 9.0 ± 15.0 ± 30.0	10 to 14 14 to 50 50 to 250 250 to 400 400 to 2000	Thrust (Z-Z)
0.4 inch double amplitude ± 3.0 ± 6.0 ± 12.0 ± 24.0	10 to 14 14 to 50 50 to 250 250 to 400 400 to 2000	Lateral (X-X and Y-Y)

* At a sweep rate of 1 octave per minute.

TABLE II

RANDOM NOISE VIBRATION

Power Spectral Density (g^2/cps)	Acceleration (g rms)	Frequency Range (cps)	Duration (minutes per axis)
0.145	6.0	20 to 250	4
0.32	24.0	250 to 2000*	4

* Roll off at 40 db/octave above 2000 cps.

3.4.2 Operating.- The P & S Conditioner shall meet the requirements of 3.2 and 3.3 during and after exposure to the following operating environmental conditions:

a. Thermal vacuum.- With the P & S Conditioner in a vacuum of less than 10^{-3} Torr, exposure of one side of the module for 6 hours to solar radiation at 1 astronomical unit (AU) while operating for a minimum duty cycle of 15 percent with an operating time of not less than 2 seconds.

3.5 Weight.- The weight of the P & S Conditioner shall be (to be determined).

3.6 Identification.- The P & S Conditioner shall be marked for identification in accordance with MIL-STD-130.

3.7 Workmanship.- The P & S Conditioner shall be fabricated and finished in such a manner that the criteria of appearance, fit,and adherence to specific tolerances shall be observed. Particular attention shall be given to the neatness and thoroughness of soldering, wiring, welding, potting, marking, plating, machine screw assemblage, freedom of parts from burrs and sharp edges, and freedom of cables from cracks and cuts.

4. QUALITY ASSURANCE PROVISIONS

4.1 Classification of tests.- The inspection and testing of the P & S Conditioner shall be classified as follows:

a. Acceptance tests (see 4.2).

b. Qualification tests (see 4.5).

c. Preservation, packaging, and packing (see 4.6).

4.2 Acceptance tests.- Each P & S Conditioner shall be subjected to the tests of Table III in the sequence shown:

TABLE III

INDIVIDUAL TESTS

Sequence	Test	Test Method Reference
1	Examination of product	4.4.1
2	Performance	4.4.2
3	Weight	4.4.4
4	Identification	4.4.5
5	Workmanship	4.4.6

4.3 Test conditions and tolerances.

4.3.1 Atmospheric conditions.- Unless otherwise specified, all tests required by this specification shall be made at an atmospheric pressure of 28 to 32 inches of mercury, a temperature of 60 to 95 degrees F, and a relative humidity of 90 percent or less.

4.3.2 Measurements.- All measurements shall be made with instruments whose accuracy has been verified in accordance with MIL-C-45662.

4.3.3 Tolerances.- Unless otherwise specified, the tolerances of all test parameters of 4.4 shall be as follows:

a. Temperature.- Under plus 100 degrees F, plus or minus 4 degrees F. Over plus 100 degrees F, plus or minus 4 percent.

b. Pressure.- Plus or minus 5 percent.

c. Vibration amplitude

(1) Random.- Plus or minus 3 decibels.

(2) Sinusoidal.- Plus or minus 10 percent.

d. Vibration frequency.- Plus or minus 2 percent.

e. Shock.- Plus or minus 10 percent.

4.3.4 Temperature source.- Unless otherwise specified, the temperature source of the test facilities shall be so located that no portion of the P & S Conditioner will be subjected to the direct temperature source during either the temperature tests or the temperature varying portions of the test cycles.

4.3.5 Protective caps.- During the environmental tests, the electrical connectors shall have protective caps properly installed in accordance with Drawing 309180 or shall be engaged with mating connectors.

CAUTION
Protective caps shall be used only on the specific P & S Conditioner with which they are delivered and shall not be used again.

4.4 Test methods.- The following test methods shall be used to verify conformance to the requirements of this specification.

4.4.1 Examination of product.- Examine each P & S Conditioner for conformance to Drawing 309180. (reference 3.2)

4.4.2 Performance tests

NOTE
Performance of the P & S Conditioner in accordance with specified requirements throughout the tests of 4.4.2 verifies compliance with 3.3.2.

4.4.2.1 Power requirement.- Connect the loads specified in 3.3.2.1, 3.3.2.2, and 3.3.2.7 to the specified P & S Conditioner terminals. Apply operating voltage as specified in 3.3.1. Monitor the operating voltage and current throughout the following performance tests to verify conformance to 3.3.1.

4.4.2.2 Operation and signals, clockwise

4.4.2.2.1 Clockwise automatic and hot gas mode operation, nozzle box pressure transducer power, and clockwise signals.- With the P & S Conditioner connected as specified in 4.4.2.1, measure the current through the low and then the high limit loads as connected across the CW pressure transducer power output terminals specified in 3.3.2.7. Monitor the current before and after application of all signals to verify conformance to 3.3.2.7. Apply "CW" and "execute" input signals in accordance with 3.3.2.1. Measure CW heater output power, CW valve power output voltage, and the respective response times to verify conformance to 3.3.2.1. Monitor the voltages at the CW valve signal output, CW heater voltage and CW heater current signal output, and nozzle box CW pressure signal output terminals for conformance to 3.3.3.1, 3.3.3.3, and 3.3.3.5 respectively. Remove the "CW" and "execute" input signals and check that the CW heater power output and the CW valve power output return to zero within the time interval specified in 3.3.2.1.

4.4.2.2.2 Hot-to-cold gas mode command, clockwise, with clockwise signals.- With the P & S Conditioner connected as specified in 4.4.2.1, apply "CW" and "execute" input signals in accordance with 3.3.2.1. Monitor the current through the low and then the high limit loads as connected across the CW pressure transducer power output terminals for conformance to 3.3.2.7. Apply a CW hot-to-cold gas mode command dc pulse as specified in 3.3.2.5. Measure the power through the CW heater power output load and the time interval for the drop to zero power to verify conformance to 3.3.2.5. Measure the CW valve signal voltage, and the CW heater voltage signal and current signal voltages, and check for conformance to 3.3.3.1 and 3.3.3.3 respectively.

4.4.2.3 Operation and signals, counterclockwise.

4.4.2.3.1 Counterclockwise automatic and hot gas mode operation, nozzle box pressure transducer power, and counterclockwise signals.- With the P & S Conditioner connected as specified in 4.4.2.1, measure the current through the low and then the high limit loads as connected across the CCW pressure transducer power output terminals specified in 3.3.2.7. Monitor the current before and after application of all signals to verify conformance to 3.3.2.7. Apply "CCW" and "execute" input signals in accordance with 3.3.2.2. Measure CCW heater output power, CCW valve power output voltage, and the respective response times to verify conformance to 3.3.2.2. Monitor the voltages at the CCW valve signal output, CCW heater voltage and CCW heater current signal output, and nozzle box CCW pressure signal output terminals for conformance to 3.3.3.2, 3.3.3.4, and 3.3.3.6 respectively. Remove the "CCW" and "execute" input signals and check that the CCW heater power output and the CCW valve power output return to zero within the time interval specified in 3.3.2.2.

4.4.2.3.2 Hot-to-cold gas mode command, counterclockwise, with counterclockwise signals.- With the P & S Conditioner connected as specified in 4.4.2.1, apply "CCW" and "execute" input signals in accordance with 3.3.2.2. Monitor the current through the low and then the high limit loads as connected across the CCW pressure transducer power output terminals for conformance to 3.3.2.7. Apply a CCW hot-to-cold gas mode command dc pulse as specified in 3.3.2.6. Measure the power through the CCW heater power output load and the time interval for the drop to zero power to verify conformance to 3.3.2.6. Measure the CCW valve signal voltage, and the CCW heater voltage signal and current signal voltages, and check for conformance to 3.3.3.2 and 3.3.3.4 respectively.

4.4.2.4 Manual mode, clockwise slew command and hot gas mode operation, clockwise hot-to-cold gas command, and clockwise signals.- With the P & S Conditioner connected as specified in 4.4.2.1 and operating in the CCW automatic and hot gas modes in accordance with 4.4.2.3.1, apply the slew command dc pulse of 3.3.2.3 to the terminals and for the minimum time specified in 3.3.2.3. Measure the CW and CCW heater power outputs, CW and CCW valve power voltage, and their response times to verify conformance to 3.3.2.3. Also check, as in 4.4.2.2.1, for conformance to the signal requirements of 3.3.3.1, 3.3.3.3, and 3.3.3.5. Apply the hot-to-cold gas mode command pulse of 3.3.2.5 for the minimum time and to the terminals specified and measure the CW heater output power for conformance to 3.3.2.5, the CW pressure transducer current through the low and high limit loads for conformance to 3.3.2.7, and the CW heater voltage and current signal voltages for conformance to 3.3.3.3; then remove the slew command pulse. Apply a second slew command pulse to the CW manual command input terminals in accordance with 3.3.2.3 and take measurements to determine that the CW outputs have de-energized as specified in 3.3.2.3. Apply the automatic mode command input pulse of 3.3.2.3 to the specified terminals for the specified time. Measure the power through the load across the CCW heater power output terminals and the voltage between the CCW valve power terminals to verify conformance to 3.3.2.3.

4.4.2.5 Manual mode, counterclockwise slew command and hot gas mode operation, counterclockwise hot-to-cold gas command, and counterclockwise signals.- With the P & S Conditioner connected as specified in 4.4.2.1 and operating in the CW automatic and hot gas modes as specified in 4.4.2.2.1, apply the slew command dc pulse of 3.3.2.4 to the terminals and for the minimum time specified in 3.3.2.4. Measure the CCW and CW heater power outputs, CCW and CW valve power voltage, and their response times to verify conformance to 3.3.2.4. Also check, as in 4.4.2.3.1, for conformance to the signal requirements of 3.3.3.2, 3.3.3.4, and 3.3.3.6. Apply the hot-to-cold gas mode command pulse of 3.3.2.6 for the minimum time and to the terminals specified and measure the CCW heater output power for conformance to 3.3.2.6, the CCW pressure transducer current through the low and high limit loads for conformance to 3.3.2.7, and the CCW heater voltage and current signal voltages for conformance to 3.3.3.4; then remove the slew command pulse. Apply a second slew command pulse to the CCW manual command input terminals in accordance with 3.3.2.4 and take measurements to determine that the CCW outputs have de-energized as specified in 3.3.2.4. Apply the automatic mode command input pulse of 3.3.2.4 to the specified terminals for the specified time. Measure the power through the load across the CW heater power output terminals and the voltage between the CW valve power terminals to verify conformance to 3.3.2.4.

4.4.3 Environmental tests

4.4.3.1 Nonoperating tests.- The P & S Conditioner shall be subjected to the following nonoperating environmental tests to verify conformance to 3.4.1.

4.4.3.1.1 Temperature (transportation, handling,and storage).- Subject the P & S Conditioner to a temperature of minus 22 plus or minus 4 degrees F for 3 hours. Raise the temperature to standard (see 4.3.1) and maintain until the temperature of the P & S Conditioner does not vary more than 2 degrees F within 15 minutes, then raise the temperature to 140 plus or minus 4 degrees F and stabilize the temperature of the P & S Conditioner as specified above. Return the temperature to standard and maintain until the P & S Conditioner temperature is stabilized as specified above. Perform the tests of 4.4.1 and 4.4.2. (reference 3.4.1.a)

4.4.3.1.2 Shock.- Subject the P & S Conditioner, through the normal mounting points or surfaces, to the Method 516, Procedure IV shock test of MIL-STD-810, except that the peak amplitude shall be 35g. Perform the tests of 4.4.1 and 4.4.2. (reference 3.4.1.b)

4.4.3.1.3 Vibration (sinusoidal).- Subject the P & S Conditioner, through the normal mounting points or surfaces, to the sinusoidal vibration sweeps defined in Table I. Perform 1 sweep through each frequency range in each direction along the axis specified in the table at a sweep rate of 1 octave per minute. Perform the tests of 4.4.1 and 4.4.2. (reference 3.4.1.c)

4.4.3.1.4 Vibration (random noise).- Subject the P & S Conditioner, through the normal mounting points or surfaces, to the random vibration specified in 3.4.1.d and Table II. Apply vibration of each spectral density for the duration shown, once along each of 3 mutually perpendicular axes. Perform the tests of 4.4.1 and 4.4.2. (reference 3.4.1.d)

4.4.3.2 Operating tests.- The P & S Conditioner shall be subjected to the following operating environmental test to verify conformance to 3.4.2.

4.4.3.2.1 Thermal vacuum.- Subject the P & S Conditioner to a vacuum of less than 10^{-3} Torr and expose one side of the module for 6 hours to a radiation of 1 solar constant (135 watts per square foot) while maintaining the duty cycle and operating time of 3.4.2.a. During this exposure, and again after it, perform the tests of 4.4.1 and 4.4.2. (reference 3.4.2.a)

4.4.4 Weight.- Weigh each P & S Conditioner and check for conformance to 3.5.

4.4.5 Identification.- Examine each P & S Conditioner and check for conformance to 3.6.

4.4.6 Workmanship.- Examine the P & S Conditioner to make certain that the requirements of 3.7 are met.

4.5 Qualification testing.

4.5.1 Qualification test samples.- The qualification test samples shall consist of specimens representative of the production equipment. They shall be tested at a laboratory designated by the procuring activity (see 6.4), or when so stated in the contract, at the contractor's plant under the supervision of the procuring activity.

4.5.2 Qualification tests.- Qualification tests shall include all tests specified under 4.4. Qualification testing shall be conducted only when and to the extent specified in the contract.

4.6 Preservation, packaging, and packing.- Inspection shall be sufficient to ensure that the requirements of Section 5 are met.

5. PREPARATION FOR DELIVERY

5.1 Preservation and packaging.- Preservation and packaging shall be Level A or C, as specified by the procuring activity.

5.1.1 Level A.- Each P & S Conditioner shall be packaged in accordance with Method IA-8 of MIL-P-116. Each module, with protective caps installed in accordance with 5.4, shall be wrapped in cushioning material conforming to PPP-C-843 to a minimum thickness of 1 inch on all sides. The module then shall be placed in a close fitting box conforming to Class 2 of PPP-B-566, PPP-B-636, or PPP-B-676.

5.1.2 Level C.- Each P & S Conditioner shall be packaged as specified in 5.1.1, except that the packaging shall conform to Method III of MIL-P-116.

5.2 Packing.- Packing shall be Levels A, B, or C, as specified by the procuring activity.

5.2.1 Level A.- The P & S Conditioners, packaged as specified in 5.1.1 or 5.1.2, shall be packed in containers conforming to Class 2 of PPP-B-636, Class 2 of PPP-B-621, or PPP-B-601 (overseas type).

5.2.2 Level B.- The P & S Conditioners, packaged as specified in 5.1.1 or 5.1.2, shall be packed in containers conforming to Class 1 of PPP-B-636, Class 1 of PPP-B-621, or PPP-B-601 (domestic type).

5.2.3 Level C.- The P & S Conditioners, packaged as specified in 5.1.1 or 5.1.2, shall be packed in a manner that will ensure carrier acceptance and safe delivery at destination. Containers shall conform to Uniform Freight Classification Rules or to regulations of other carriers applicable to the mode of transportation.

5.3 Marking.- In addition to any special marking required by the contract or order, all interior and shipping containers shall be marked in accordance with MIL-STD-129.

5.4 Special handling.- When packaging the P & S Conditioner, the protective caps shall be installed in accordance with Drawing 309180.

6. NOTES

6.1 Intended use.- The P & S Conditioner covered by this specification is intended for use in the ATS-IV resistojet thrustor system as a processor of logic signals and telemetry commands, a power supply for transducers, a limited output amplifier for pressure sensor signals, and to provide monitoring signals for the control elements of a stable platform type satellite.

6.2 Ordering data.- Procurement documents should specify the following:

a. The title, number, and date of this specification.

b. Applicable stock number.

c. Serialization requirements.

d. The level of preservation, packaging, and packing.

e. Whether design qualification tests are required, and the number of qualification test specimens to be submitted.

6.3 Definitions.- For the purposes of this specification, the following definitions apply:

6.3.1 Input signal.- An electrical control input generated by another module within the resistojet thrustor system.

6.3.2 Command input.- An electrical control input generated by a telemetry or other control link for changing the mode of system operation.

6.3.3 Output signal.- An electrical signal that monitors the magnitude or condition of a system parameter when read out through a continuous or commutated telemetry link.

6.3.4 Power output.- A voltage, current, or power regulated electrical output for performing a modular or system function.

6.4 Procuring activity.- For the purposes of this specification, the procuring activity shall be defined as the National Aeronautics and Space Administration (NASA) or other Department of Defense Activity responsible for the Mod III contract.

APPENDIX C

MODEL SPECIFICATIONS FOR STATION-KEEPING MODULE, MOD III

APPENDIX C

MODEL SPECIFICATIONS FOR STATION-KEEPING MODULE,

MOD III

1. SCOPE.- This specification covers one type of equipment designated as Station Keeping Module, Mod III. The Mod III Station Keeping Module accepts telemetry command signals and responds by energizing positive and negative thrustor heaters and flow valves in optimum sequence.

2. APPLICABLE DOCUMENTS

2.1 Government documents.- The following Government documents of the issues in effect on the date of this specification form a part of this specification to the extent specified herein.

SPECIFICATIONS

Federal

PPP-B-566	Boxes, Folding, Paperboard
PPP-B-601	Boxes, Wood, Cleated-Plywood
PPP-B-621	Boxes, Wood, Nailed and Lock-Corner
PPP-B-636	Boxes, Fiberboard
PPP-B-676	Boxes, Set-Up, Paperboard
PPP-C-843	Cushioning Material, Cellulosic

Military

MIL-P-116	Preservation, Methods of
MIL-C-45662	Calibration of Standards

STANDARDS

Military

MIL-STD-129	Marking for Shipment and Storage

STANDARDS

Military

MIL-STD-130	Identification Marking of U.S. Military Property
MIL-STD-810	Environmental Test Methods for Aerospace and Ground Equipment

(Copies of documents required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 Non-Government documents.- The following non-Government documents of the issues in effect on the date of this specification form a part of this specification to tht extent specified herein.

2.2.1 Avco-Space Systems Division

DRAWING

309130	Station Keeping Module, ATS-IV

(Application for copies should be addressed to Avco Corporation, Space Systems Division, Lowell Industrial Park, Lowell, Massachusetts, 01851.)

2.2.2 Uniform Freight Classification Committee

HANDBOOK

Uniform Freight Classification Rules

(Application for copies should be addressed to Uniform Freight Classification Committee, 202 Chicago Union Station, Chicago 6, Illinois.)

3. REQUIREMENTS

3.1 Design qualification.- This specification makes provisions for qualification testing.

3.2 Design and construction.- The design and construction of the Station Keeping Module, Part Number 309130-1, shall be in accordance with Drawing 309130.

3.3 Performance

3.3.1 Power requirement.- When connected to the appropriate output loads specified herein, the Station Keeping Module shall operate on a current not exceeding 600 milliamperes from a direct current (dc) source of 28.0 plus or minus 2.8 volts, as applied through terminals J1-15, J1-28 and J1-29 (positive) and J1-3, J1-21 and J1-22 (negative).

3.3.2 Operation

3.3.2.1 Positive thrustor circuit.- The positive thrustor input, terminals J1-30 (positive) and J1-22 (negative), shall have a resistive impedance of 1000 plus or minus 100 ohms. Application of plus 5.0 plus or minus 0.5 volts dc across these terminals shall result in a square wave alternating current power output of 7.50 plus or minus 0.75 watt within the frequency range of 6 to 8 kilocycles (kc) into a 0.100 plus or minus 0.001 ohm load across output (positive heater) terminals E-1 and E-2. Additionally, within 1.0 plus or minus 0.1 second, the Station Keeping Module shall deliver 27.0 plus or minus 3.8 volts dc across a 280 plus or minus 56 ohm load connected to output (positive flow valve) terminals J1-24 (positive) and J1-22 (negative).

3.3.2.2 Negative thrustor circuit.- The negative thrustor input, terminals J1-31 (positive) and J1-22 (negative), shall have a resistive impedance of 1000 plus or minus 100 ohms. Application of plus 5.0 plus or minus 0.5 volts dc across these terminals shall result in operation identical to 3.3.2.1, except as follows:

a. The 0.100 plus or minus 0.001 ohm (negative heater) load shall be across output terminals E-3 and E-4.

b. The 280 plus or minus 56 ohm (negative flow valve) load shall be across output terminals J1-33 (positive) and J1-22 (negative).

3.3.2.3 Cold gas command circuit.- The cold gas command input, terminals J1-34 (positive) and J1-22 (negative) shall have a resistive impedance of 1000 plus or minus 100 ohms. Application of plus 5.0 plus or minus 0.5 volts dc across these terminals shall result in zero power output (prevent power generation) into the 0.100 plus or minus 0.001 ohm heater loads during the operation of the positive thrustor circuit as specified in 3.3.2.1 and of the negative thrustor circuit as specified in 3.3.2.2.

3.3.3 Monitoring

3.3.3.1 Thrustors

3.3.3.1.1 Current (both thrustors).- During operation of the positive or negative thrustors in accordance with 3.3.2.1 and 3.3.2.2 respectively, 2.70 plus or minus 0.25 volts dc shall be delivered across monitor terminals J1-36 (positive) and J1-22 (negative) to indicate that correct operating current is flowing in the corresponding (positive or negative) heater load.

3.3.3.1.2 Voltage (positive thrustor).- During operation of the positive thrustor circuit in accordance with 3.3.2.1, 3.90 plus or minus 0.40 volts dc shall be delivered across monitor terminals J1-35 (positive) and J1-22 (negative) to indicate that correct voltage is appearing across the positive heater load.

3.3.3.1.3 Voltage (negative thruster).- During operation of the negative thrustor circuit in accordance with 3.3.2.2, 3.90 plus or minus 0.40 volts dc shall be delivered across monitor terminals J1-37 (positive) and J1-22 (negative) to indicate that correct voltage is appearing across the negative heater load.

3.3.3.2 Flow valves.

3.3.3.2.1 Voltage (positive flow valve).- During operation of the positive thrustor circuit in accordance with 3.3.2.1, and of the positive cold gas command circuit in accordance with 3.3.2.3, 2.55 plus or minus 0.25 volts dc shall be delivered across monitor terminals J1-2 (positive) and J1-22 (negative) to indicate that correct voltage is appearing across the positive flow valve load.

3.3.3.2.2 Voltage (negative flow valve).- During operation of the negative thrustor circuit in accordance with 3.3.2.2 and of the negative cold gas command circuit in accordance with 3.3.2.4, 2.55 plus or minus 0.25 volts dc shall be delivered across monitor terminals J1-23 (positive) and J1-22 (negative) to indicate that correct voltage is appearing across the negative flow valve load.

3.3.3.3 Nozzle boxes.

3.3.3.3.1 Pressure (positive nozzle box).- Upon application of 50.0 plus or minus 2.5 millivolts dc signals to positive nozzle box pressure sensor terminals J1-10 (positive) and J1-11 (negative), 5.00 plus or minus 0.25 volts dc shall be delivered across monitor terminals J1-12 (positive) and J1-22 (negative) to indicate that the positive nozzle pressure is at the correct operating level.

3.3.3.3.2 Pressure (negative nozzle box).- Upon application of 50.0 plus or minus 2.5 millivolts dc signals to negative nozzle box pressure sensor terminals J1-5 (positive) and J1-8 (negative), 5.00 plus or minus 0.25 volts dc shall be delivered across monitor terminals J1-6 (positive) and J1-22 (negative) to indicate that the negative nozzle pressure is at the correct operating level.

3.4 Environments

3.4.1 Nonoperating.- The Station Keeping Module shall meet the requirements of 3.2 and 3.3 after exposure to the following nonoperating environmental conditions.

a. Temperature (transportation, handling, and storage).- Minus 22 plus or minus 4 degrees Fahrenheit (F) to plus 140 plus or minus 4 degrees F.

b. Shock.- Exposure to a 35g triangular shock pulse of 10 milliseconds (ms) along each of 3 mutually perpendicular axes.

c. Vibration (sinusoidal).- Exposure to sinusoidal vibration as specified in Table I along the axes shown.

TABLE I

SINUSOIDAL VIBRATION

Vibratory Acceleration Zero to Peak g*	Frequency Range (cps)	Axis
0.4 inch double amplitude	10 to 14	Thrust (Z-Z)
$\pm$ 4.0	14 to 50	
$\pm$ 9.0	50 to 250	
$\pm$ 15.0	250 to 400	
$\pm$ 30.0	400 to 2000	
0.4 inch double amplitude	10 to 14	
$\pm$ 3.0	14 to 50	
$\pm$ 6.0	50 to 250	
$\pm$ 12.0	250 to 400	Lateral
$\pm$ 24.0	400 to 2000	(X-X and Y-Y)

* At a sweep rate of 1 octave per minute.

d. Vibration (random noise).- Exposure along each of 3 mutually perpendicular axes to Gaussian random vibration as specified in Table II, with g-peaks clipped at 3 times the root-mean-square (rms) acceleration.

TABLE II

RANDOM NOISE VIBRATION

Power Spectral Density (g^2/cps)	Acceleration (g rms)	Frequency Range (cps)	Duration (minutes per axis)
0.145 0.32	6.0 24.0	20 to 250 250 to 2000*	4 4
* Roll off at 40 db/octave above 2000 cps.			

3.4.2 Operating.- The Station Keeping Module shall meet the requirements of 3.2 and 3.3 during and after exposure to the following operating environmental conditions:

a. Thermal vacuum.- With the Station Keeping Module in a vacuum of less than 10^{-3} Torr, exposure of one side of the module for 6 hours to solar radiation at 1 astronomical unit (AU) while operating for a minimum duty cycle of 15 percent with an operating time of not less than 2 seconds.

3.5 Weight.- The weight of the Station Keeping Module shall be (to be determined).

3.6 Identification.- The Station Keeping Module shall be marked for identification in accordance with MIL-STD-130.

3.7 Workmanship.- The Station Keeping Module shall be fabricated and finished in such a manner that the criteria of appearance, fit,and adherence to specific tolerances shall be observed. Particular attention shall be given to the neatness and thoroughness of soldering, wiring, welding, potting, marking, plating, machine screw assemblage, freedom of parts from burrs and sharp edges, and freedom of cables from cracks and cuts.

4. QUALITY ASSURANCE PROVISIONS

4.1 Classification of tests.- The inspection and testing of the Station Keeping Module shall be classified as follows:

a. Acceptance tests (see 4.2).

b. Qualification tests (see 4.5).

c. Preservation, packaging,and packing tests (see 4.6).

4.2 Acceptance tests.- Each Station Keeping Module shall be subjected to the tests of Table III in the sequence shown.

TABLE III

INDIVIDUAL TESTS

Sequence	Test	Test Method Reference
1	Examination of product	4.4.1
2	Performance	4.4.2
3	Weight	4.4.4
4	Identification	4.4.5
5	Workmanship	4.4.6

4.3 Test conditions and tolerances.

4.3.1 Atmospheric conditions.- Unless otherwise specified, all tests required by this specification shall be made at an atmospheric pressure of 28 to 32 inches of mercury, a temperature of 60 to 95 degrees F, and a relative humidity of 90 percent or less.

4.3.2 Measurements.- All measurements shall be made with instruments whose accuracy has been verified in accordance with MIL-C-45662.

4.3.3 Tolerances.- Unless otherwise specified, the tolerances of all test parameters of 4.4 shall be as follows:

a. Temperature.- Under plus 100 degrees F, plus or minus 4 degrees F. Over plus 100 degrees F, plus or minus 4 percent.

b. Pressure.- Plus or minus 5 percent.

c. Vibration amplitude.-

(1) Random.- Plus or minus 3 decibels.

(2) Sinusoidal.- Plus or minus 10 percent.

d. Vibration frequency.- Plus or minus 2 percent.

e. Shock.- Plus or minus 10 percent.

4.3.4 Temperature source.- Unless otherwise specified, the temperature source of the test facilities shall be so located that no portion of the Station Keeping Module will be subjected to the direct temperature source during either the temperature tests or the temperature varying portions of the test cycles.

4.3.5 Protective caps.- During the environmental tests, the connectors shall have protective caps properly installed in accordance with Drawing 309130 or shall be engaged with mating connectors.

CAUTION

Protective caps shall be used only on the specific Station Keeping Module with which they are delivered and shall not be used again.

4.4 Test methods.- The following test methods shall be used to verify conformance to the requirements of this specification.

4.4.1 Examination of product.- Examine each Station Keeping Module for conformance to Drawing 309130. (reference 3.2)

4.4.2 Performance tests

4.4.2.1 Power requirement.- Connect resistive loads as specified in 3.3.2.1 and 3.3.2.2 between the specified heater and flow valve terminals of the positive and negative thrustor circuits. Apply 30.8 volts dc across the power input terminals as specified in 3.3.1 and measure the current to verify conformance to 3.3.1.

4.4.2.2 Positive thrustor circuit

4.4.2.2.1 Input resistance.- With the Station Keeping Module unenergized, measure the dc input resistance of the positive thrustor circuit, observing the polarity specified in 3.3.2.1. Check the resistance value for conformance to 3.3.2.1.

4.4.2.2.2 Operation and monitoring.- Connect the loads specified in 3.3.2.1 between the specified positive heater terminals and positive flow valve terminals. Apply operating power as specified in 3.3.1 and input signals in accordance with 3.3.2.1. With an oscilloscope or other suitable measuring device, measure the voltage and frequency of the square wave output developed across the positive heater terminals and measure or calculate the power output to verify conformance to 3.3.2.1. Measure the delay time and the voltage developed across the positive flow valve terminals for compliance with 3.3.2.1. Measure the voltage and check the polarity between the monitoring terminals of 3.3.3.1.1, 3.3.3.1.2, 3.3.3.2.1, and 3.3.3.3.1. Check for conformance to 3.3.2.1, 3.3.3.1.1, 3.3.3.1.2, 3.3.3.2.1, and 3.3.3.3.1.

4.4.2.3 Negative thrustor circuit.

4.4.2.3.1 Input resistance.- With the Station Keeping Module unenergized, measure the dc input resistance of the negative thrustor circuit, observing the polarity specified in 3.3.2.2, Check the resistance value for conformance to 3.3.2.2.

4.4.2.3.2 Operation and monitoring.- Connect the loads specified in 3.3.2.2 between the specified negative heater terminals and negative flow valve terminals. Apply operating power as specified in 3.3.1 and input signals in accordance with 3.3.2.2. With an oscilloscope or other suitable measuring device, measure the voltage and frequency of the squarewave output developed across the negative heater terminals and measure or calculate the power output to verify conformance to 3.3.2.2. Measure the delay time and the voltage developed across the negative flow valve terminals for compliance with 3.3.2.2. Measure the voltage and check the polarity between the monitoring terminals of 3.3.3.1.1, 3.3.3.1.3, 3.3.3.2.2, and 3.3.3.3.2. Check for conformance to 3.3.2.2, 3.3.3.1.1, 3.3.3.1.3, 3.3.3.2.2, and 3.3.3.3.2.

4.4.2.4 Cold gas command circuit.

4.4.2.4.1 Input resistance.- With the Station Keeping Module unenergized, measure the dc input resistance of the cold gas command circuit, observing the polarity specified in 3.3.2.3. Check the resistance value for conformance to 3.3.2.3.

4.4.2.4.2 Operation and monitoring.- Connect the loads specified in 3.3.2.1 and 3.3.2.2 between the specified positive and negative heater terminals and positive and negative flow valve terminals. Apply operating power as specified in 3.3.1 and a thrustor input signal in accordance with 3.3.2.1. Measure the voltage between the positive heater terminals of 3.3.2.1 to ascertain that zero power is developed across these terminals as specified in 3.3.2.3. Measure the voltage and check the polarity between the monitoring terminals of 3.3.3.2.1 and 3.3.3.3.1. Remove the input signal of 3.3.2.1 and apply an input signal in accordance with 3.3.2.2. Measure the voltage between the negative heater terminals of 3.3.2.2 to ascertain that zero power is developed across these terminals as specified in 3.3.2.3. Measure the voltage and check the polarity between the monitoring terminals of 3.3.3.2.2 and 3.3.3.3.2. Check for conformance to 3.3.2.3, 3.3.3.2.1, 3.3.3.2.2, 3.3.3.3.1, and 3.3.3.3.2 as applicable to positive and negative thrustor circuit operation.

4.4.3 Environmental tests

4.4.3.1 Nonoperating tests.- The Station Keeping Module shall be subjected to the following nonoperating environmental tests to verify conformance to 3.4.1.

4.4.3.1.1 Temperature (transportation, handling, and storage).- Subject the Station Keeping Module to a temperature of minus 22 plus or minus 4 degrees F for 3 hours. Raise the temperature to standard (see 4.3.1) and maintain until the temperature of the Station Keeping Module does not vary more than 2 degrees F within 15 minutes, then raise the temperature to 140 plus or minus 4 degrees F and stabilize the temperature of the Station Keeping Module as specified above. Return the temperature to standard and maintain until the Station Keeping Module temperature is stabilized as specified above. Perform the tests of 4.4.1 and 4.4.2. (reference 3.4.1.a)

4.4.3.1.2 Shock.- Subject the Station Keeping Module, through its mounting points, to the Method 516, Procedure IV shock test of MIL-STD-810, except that the peak intensity shall be 35g. Perform the tests of 4.4.1 and 4.4.2. (reference 3.4.1.b)

4.4.3.1.3 Vibration (sinusoidal).- Subject the Station Keeping Module, through the normal mounting points or surfaces, to the sinusoidal vibration sweeps defined in Table I. Perform 1 sweep through each frequency range in each direction along the axis specified in the table at a sweep rate of 1 octave per minute. Perform the tests of 4.4.1 and 4.4.2. (reference 3.4.1.c)

4.4.3.1.4 Vibration (random noise).- Subject the Station Keeping Module, through the normal mounting points or surfaces, to the random vibration specified in 3.4.1.d and Table II. Apply vibration of each spectral density for the duration shown, once along each of 3 mutually perpendicular axes. Perform the tests of 4.4.1 and 4.4.2. (reference 3.4.1.d)

4.4.3.2 Operating tests.- The Station Keeping Module shall be subjected to the following operating environmental test to verify conformance to 3.4.2.

4.4.3.2.1 Thermal-vacuum.- Subject the Station Keeping Module to a vacuum of less than 10^{-3} Torr. While in this vacuum, expose one side of the module for 6 hours to a radiation intensity of 1 solar constant (135 watts per square foot). During this environmental exposure, perform the test of 4.4.2 and maintain the operating duty cycle of 3.4.2.a. After this environmental exposure, perform the tests of 4.4.1 and 4.4.2. (reference 3.4.2.a)

4.4.4 Weight.- Weigh each Station Keeping Module and check for conformance to 3.5.

4.4.5 Identification.- Examine each Station Keeping Module and check for conformance to 3.6.

4.4.6 Workmanship.- Examine the Station Keeping Module to make certain that the requirements of 3.7 are met.

4.5 Qualification testing.

4.5.1 Qualification test samples.- The qualification test samples shall consist of models representative of the production equipment. They shall be tested at a laboratory designated by the procuring activity (see 6.3), or when so stated in the contract, at the contractor's plant under the supervision of the procuring activity.

4.5.2 Qualification tests.- Qualification tests shall include all tests specified under 4.4. Qualification testing shall be conducted only when and to the extent specified in the contract.

4.6 Preservation, packaging, and packing.- Inspection shall be sufficient to ensure that the requirements of Section 5 are met.

5. PREPARATION FOR DELIVERY

5.1 Preservation and packaging.- Preservation and packaging shall be Level A or C, as specified by the procuring activity.

5.1.1 Level A.- Each Station Keeping Module shall be packaged in accordance with Method IA-8 of MIL-P-116. Each module, with protective caps installed in accordance with 5.4, shall be wrapped in cushioning material conforming to PPP-C-843 to a minimum thickness of 1 inch on all sides. The module then shall be placed in a close fitting box conforming to Class 2 of PPP-B-566, PPP-B-636 or PPP-B-676.

5.1.2 Level C.- Each Station Keeping Module shall be packaged as specified in 5.1.1, excpet that the packaging shall conform to Method III of MIL-P-116.

5.2 Packing.- Packing shall be Level A, B, or C, as specified by the procuring activity.

5.2.1 Level A.- The Station Keeping Modules, packaged as specified in 5.1.1 or 5.1.2, shall be packed in containers conforming to Class 2 of PPP-B-636, Class 2 of PPP-B-621, or PPP-B-601 (overseas type).

5.2.2 Level B.- The Station Keeping Modules, packaged as specified in 5.1.1 or 5.1.2, shall be packed in containers conforming to Class 1 of PPP-B-636, Class 1 of PPP-B-621, or PPP-B-601 (domestic type).

5.2.3 Level C.- The Station Keeping Modules, packaged as specified in 5.1.1 or 5.1.2, shall be packed in a manner that will ensure carrier acceptance and safe delivery at destination. Containers shall conform to Uniform Freight Classification Rules or to regulations of other carriers applicable to the mode of transportation.

5.3 Marking.- In addition to any special marking required by the contract or order, all interior and shipping containers shall be marked in accordance with MIL-STD-129.

5.4 Special handling.- When packaging the Station Keeping Module, the protective caps shall be installed in accordance with Drawing 309130.

6. NOTES

6.1 Intended use.- The Station Keeping Module covered by this specification is intended for use in the ATS-IV resisto-jet thrustor system as a control element for two direction station keeping of a stable platform type satellite.

6.2 Ordering data.- Procurement documents should specify the following:

a. The title, number, and date of this specification.

b. Applicable stock number.

c. Serialization requirements.

d. The level of preservation, packaging, and packing.

e. Whether design qualification tests are required, and the number of qualification test specimens to be submitted.

6.3 Procuring activity.- For the purposes of this specification, the procuring activity shall be defined as the National Aeronautics and Space Administration (NASA) or other Department of Defense Activity responsible for the Mod III contract.

APPENDIX D

MODEL SPECIFICATIONS FOR THE SUPPLY SIGNAL-CONDITIONING MODULE, MOD III

APPENDIX D

MODEL SPECIFICATIONS FOR THE

SUPPLY SIGNAL-CONDITIONING MODULE,

MOD III

1. SCOPE.- This specification covers one type of equipment designated as Supply Signal Conditioning Module, Mod III. The Mod III Supply Signal Conditioning Module (hereinafter referred to as the Supply Signal Conditioner) accepts signals from pressure and temperature sensors and amplifies these signals to provide corresponding direct current outputs within a predetermined uniform voltage range. The Supply Signal Conditioner serves also as a multi-output power source and provides an on/off monitor signal for a regulator valve.

2. APPLICABLE DOCUMENTS

2.1 Government documents.- The following Government documents of the issues in effect on the date of this specification form a part of this specification to the extent specified herein.

SPECIFICATIONS

Federal

PPP-B-566	Boxes, Folding, Paperboard
PPP-B-601	Boxes, Wood, Cleated-Plywood
PPP-B-621	Boxes, Wood, Nailed and Lock-Corner
PPP-B-636	Boxes, Fiberboard
PPP-B-676	Boxes, Set-Up, Paperboard
PPP-C-843	Cushioning Material, Cellulosic

Military

MIL-P-116	Preservation, Methods of
MIL-C-45662	Calibration of Standards

STANDARDS

Military

MIL-STD-129	Marking for Shipment and Storage
MIL-STD-130	Identification Marking of U.S. Military Property
MIL-STD-810	Environmental Test Methods for Aerospace and Ground Equipment

(Copies of documents required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 Non-Government documents.- The following non-Government documents of the issues in effect on the date of this specification form a part of this specification to the extent specified herein.

2.2.1 Avco-Space Systems Division

DRAWING

309229	Supply Signal Conditioning Module, ATS-IV

(Application for copies should be addressed to Avco Corporation, Space Systems Division, Lowell Industrial Park, Lowell, Massachusetts, 01851.)

2.2.2 Uniform Freight Classification Committee

HANDBOOK

Uniform Freight Classification Rules

(Application for copies should be addressed to Uniform Freight Classification Committee, 202 Chicago Union Station, Chicago 6, Illinois.)

3. REQUIREMENTS

3.1 Design qualification.- This specification makes provisions for qualification testing.

3.2 Design and construction.- The design and construction of the Supply Signal Conditioner, Part Number 309229-1, shall be in accordance with Drawing 309229.

3.3 Performance

3.3.1 Power requirement.- The Supply Sigal Conditioner shall operate on a current not exceeding 250 milliamperes from a direct current (dc) source of 28.0 plus or minus 2.8 volts, as applied through terminals J1-4 and J1-13 (positive) and J1-3 and J1-19 (negative).

3.3.2 Operation.- The Supply Signal Conditioner, when operating in accordance with 3.3.1, shall perform as follows:

3.3.2.1 Power source (pressure regulation system).- The Supply Signal Conditioner shall supply up to 3.1 watts of dc power at 28.0 plus or minus 2.8 volts across power output terminals J1-9 and J1-10 (positive) and J1-19 (negative).

3.3.2.2 Constant current sources.- The Supply Signal Conditioner shall provide 3 discrete constant current outputs, each of 15.00 plus or minus 0.75 milliamperes dc into 400 to 700 ohm variable resistive loads across each of the following sets of terminals.

3.3.2.2.1 Supply pressure transducer.- Terminal J1-23 (positive) and J1-19 (negative).

3.3.2.2.2 Preplenum pressure transducer.- Terminal J1-12 (positive) and J1-19 (negative).

3.3.2.2.3 Plenum pressure transducer.- Terminal J1-24 (positive) and J1-19 (negative).

3.3.2.3 Regulated voltage source (plenum temperature circuit amplifier).- With variable load resistances in the range of 1680 to 15400 ohms shunted across thermistor terminals J1-8 (positive) and J1-19 (negative), the plenum temperature amplifier shall develop dc output voltages across terminals J1-11 (positive) and J1-19 (negative) in accordance with Table I. Additionally, the output voltage shall not exceed under any conditions the range limited by plus 5.25 and minus 0.4 volts.

TABLE I

REGULATED VOLTAGE LOADS AND OUTPUTS

Load Resistance (ohms)	Ideal Output (volts)	Tolerance (millivolts)
15400	0.00	±30
9360	+1.83	±30
5830	+3.00	±30
3750	+3.72	±30
2480	+4.18	±30
1680	+4.47	±30

3.3.2.4 Supply pressure amplifier.- Application of a differential dc input voltage to (supply pressure) input terminals J1-5 (positive) and J1-21 (negative) shall result in a voltage gain of 10 to output terminals J1-15 (positive) and J1-19 (negative), except that in no case shall the output voltage exceed the range limited by minus 0.40 volt and plus 5.25 volts, and that within the range of plus 0.50 volt and plus 4.80 volts, the output voltage at any point shall not deviate by more than plus or minus 0.05 volt from the value based upon the gain specified above.

3.3.2.5 Preplenum pressure amplifier.- Application of a differential dc input voltage to (preplenum pressure) input terminals J1-2 (positive) and J1-7 (negative) shall result in a voltage gain of 33.2 to output terminals J1-6 (positive) and J1-19 (negative), except that in no case shall the output voltage exceed the range limited by minus 0.40 volt and plus 5.25 volts, and that within the range of plus 0.50 volt and plus 4.80 volts, the output voltage at any point shall not deviate by more than plus or minus 0.05 volt from the value based upon the gain specified above.

3.3.2.6 Plenum pressure amplifier.- Application of a differential dc input voltage to (plenum pressure) input terminals J1-14 (positive) and J1-17 (negative) shall result in a voltage gain of 100 to output terminals J1-16 (positive) and J1-19 (negative), except that in no case shall the output voltage exceed the range limited by minus 0.40 volt and plus 5.25 volts, and that within the range of plus 0.50 volt and plus 4.80 volts, the output voltage at any point shall not deviate by more than plus or minus 0.05 volt from the value based upon the gain specified above.

3.3.2.7 Monitor signal (regulator valve).- Application of a short circuit across pressure switch terminals J1-10 and J1-20 shall produce 2.55 plus or minus 0.26 volts dc between regulator valve monitor signal output terminals J1-21 (positive) and J1-19 (negative). In the absence of a short circuit across the pressure switch terminals, the output voltage shall be zero.

3.4 Environments

3.4.1 Nonoperating.- The Supply Signal Conditioner shall meet the requirements of 3.2 and 3.3 after exposure to the following nonoperating environmental conditions:

a. Temperature (transportation, handling, and storage).- Minus 22 plus or minus 4 degrees Fahrenheit (F) to plus 140 plus or minus 4 degrees F.

b. Shock.- Exposure to a 35g triangular shock pulse of 10 milliseconds (ms) along each of 3 mutually perpendicular axes.

c. Vibration (sinusoidal).- Exposure to sinusoidal vibration as specified in Table II along the axes shown.

TABLE II

SINUSOIDAL VIBRATION

Vibratory Acceleration Zero to Peak g*	Frequency Range (cps)	Axis
0.4 inch double amplitude	10 to 14	Thrust (Z-Z)
± 4.0	14 to 50	
± 9.0	50 to 250	
± 15.0	250 to 400	
± 30.0	400 to 2000	
0.4 inch double amplitude	10 to 14	Lateral (X-X and Y-Y)
± 3.0	14 to 50	
± 6.0	50 to 250	
± 12.0	250 to 400	
± 24.0	400 to 2000	

* At a sweep rate of 1 octave per minute.

d. Vibration (random noise).- Exposure along each of 3 mutually perpendicular axes to Gaussian random vibration as specified in Table III, with g-peaks clipped at 3 times the root-mean-square (rms) acceleration.

TABLE III

RANDOM NOISE VIBRATION

Power Spectral Density (g^2/cps)	Acceleration (g rms)	Frequency Range (cps)	Duration (minutes per axis)
0.145	6.0	20 to 250	4
0.32	24.0	250 to 2000*	4
* Roll off at 40 db/octave above 2000 cps.			

3.4.2 Operating.- The Supply Signal Conditioner shall meet the requirements of 3.2 and 3.3 during and after exposure to the following operating environmental conditions:

a. Thermal-vacuum.- With the Supply Signal Conditioner in a vacuum of less than 10^{-3} Torr, exposure of one side of the module for 6 hours to solar radiation at 1 astronomical unit (AU) while operating for a minimum duty cycle of 15 percent with an operating time of not less than 2 seconds.

3.5 Weight.- The weight of the Supply Signal Conditioner shall be (to be determined).

3.6 Identification.- The Supply Signal Conditioner shall be marked for identification in accordance with MIL-STD-130.

3.7 Workmanship.- The Supply Signal Conditioner shall be fabricated and finished in such a manner that the criteria of appearance, fit,and adherence to specific tolerances shall be observed. Particular attention shall be given to the neatness and thoroughness of soldering, welding, wiring, potting, marking, plating, machine screw assemblage, freedom of parts from burrs and sharp edges, and freedom of cables from cracks and cuts.

4. QUALITY ASSURANCE PROVISIONS

4.1 Classification of tests.- The inspection and testing of the Supply Signal Conditioner shall be classified as follows:

a. Acceptance tests (see 4.2).

b. Qualification tests (see 4.5).

c. Preservation, packaging,and packing (see 4.6).

4.2 Acceptance tests.- Each Supply Signal Conditioner shall be subjected to the tests of Table IV in the sequence shown:

TABLE IV

INDIVIDUAL TESTS

Sequence	Test	Test Method Reference
1	Examination of product	4.4.1
2	Performance	4.4.2
3	Weight	4.4.4
4	Identification	4.4.5
5	Workmanship	4.4.6

4.3 Test conditions and tolerances.

4.3.1 Atmospheric conditions.- Unless otherwise specified, all tests required by this specification shall be made at an atmospheric pressure of 28 to 32 inches of mercury, a temperature of 60 to 95 degrees F and a relative humidity of 90 percent or less.

4.3.2 Measurements.- All measurements shall be made with instruments whose accuracy has been verified in accordance with MIL-C-45662.

4.3.3 Tolerances.- Unless otherwise specified, the tolerances of all test parameters of 4.4 shall be as follows:

a. Temperature.- Under plus 100 degrees F, plus or minus 4 degrees F. Over plus 100 degrees F, plus or minus 4 percent.

b. Pressure.- Plus or minus 5 percent.

c. Vibration amplitude

(1) Random.- Plus or minus 3 decibels.

(2) Sinusoidal.- Plus or minus 10 percent.

d. Vibration frequency.- Plus or minus 2 percent.

e. Shock.- Plus or minus 10 percent.

4.3.4 Temperature source.- Unless otherwise specified, the temperature source of the test facilities shall be so located that no portion of the Supply Signal Conditioner will be subjected to the direct temperature source during either the temperature tests or the temperature varying portions of the test cycles.

4.3.5 Protective caps.- During the environmental tests, the connectors shall have protective caps properly installed in accordance with Drawing 309229 or shall be engaged with mating connectors.

CAUTION

Protective caps shall be used only on the specific Supply Signal Conditioner with which they are delivered and shall not be used again.

4.4 Test methods.- The following test methods shall be used to verify conformance to the requirements of this specification.

4.4.1 Examination of product.- Examine each Supply Signal Conditioner for conformance to Drawing 309229. (reference 3.2)

4.4.2 Performance tests

4.4.2.1 Power requirement, power source, and monitor signal.- Connect the minimum loads of 3.3.2.2 and the maximum loads of 3.3.2.3 through 3.3.2.6 to the specified output terminals of the Supply Signal Conditioner and short circuit the monitor output terminals of 3.3.2.7. Apply 25.2 volts dc to the terminals specified in 3.3.1 and measure the current flowing in this circuit while simultaneously measuring the maximum obtainable power output across the terminals specified in 3.3.2.1 and the voltage across the monitor signal output terminals of 3.3.2.7. Check for conformance to 3.3.1, 3.3.2.1 and 3.3.2.7. Repeat this test, using the maximum loads of 3.3.2.2, the minimum loads of 3.3.2.3 through 3.3.2.6, an open circuit across the monitor signal output terminals of 3.3.2.7, and 30.8 volts dc applied through the terminals specified in 3.3.1. Check for conformance to 3.3.1, 3.3.2.1 and 3.3.2.7.

4.4.2.2 Constant current sources (supply pressure, preplenum pressure, and plenum pressure transducers).- Connect 300 ohm loads across the output terminals specified in 3.3.2.2.1, 3.3.2.2.2 and 3.3.2.2.3. With the Supply Signal Conditioner operating in accordance with 3.3.1 on 25.2 volts dc, measure the current flowing in each of the loads and check for conformance to 3.3.2.2.1, 3.3.2.2.2 and 3.3.2.2.3 respectively. Disconnect the 300 ohm resistors and replace them with 500-ohm load resistors. Measure the current flowing in each of the loads and check for conformance to 3.3.2.2.1, 3.3.2.2.2 and 3.3.2.2.3 respectively. Repeat this test with 30.8 volts dc applied to the terminals specified in 3.3.1 and check for conformance to 3.3.2.2.1, 3.3.2.2.2 and 3.3.2.2.3.

4.4.2.3 Regulated voltage source.- Successively shunt resistive loads of the values specified in Table I across the thermistor output terminals specified in 3.3.2.3. With the Supply Signal Conditioner operating in accordance with 3.3.1 on 25.2 volts dc, measure the voltage across each load in turn. Compliance with the output voltages and tolerances of Table I indicates conformance to 3.3.2.3. Repeat this test with 30.8 volts dc applied to the terminals specified in 3.3.1 and check for conformance to 3.3.2.3.

4.4.2.4 Supply pressure amplifier.- With the Supply Signal Conditioner operating in accordance with 3.3.1 on 25.2 volts dc, apply a minimum of 5 different dc input voltages in the range of 0 to plus 575 millivolts to the supply pressure input terminals specified in 3.3.2.4 and measure the resulting output voltages across the specified output terminals. Check voltage gain and output voltage for conformance to 3.3.2.4. Repeat this test with 30.8 volts dc applied to the terminals specified in 3.3.1 and check for conformance to 3.3.2.4.

4.4.2.5 Preplenum pressure amplifier.- With the Supply Signal Conditioner operating in accordance with 3.3.1 on 25.2 volts dc, apply a minimum of 5 different dc input voltages in the range of 0 to plus 175 millivolts to the preplenum pressure input terminals specified in 3.3.2.5 and measure the resulting output voltages across the specified output terminals. Check voltage gain and output voltage for conformance to 3.3.2.5. Repeat this test with 30.8 volts dc applied to the terminals specified in 3.3.1 and check for conformance to 3.3.2.5.

4.4.2.6 Plenum pressure amplifier.- With the Supply Signal Conditioner operating in accordance with 3.3.1 on 25.2 volts dc, apply a minimum of 5 different dc input voltages in the range of 0 to plus 58 millivolts to the plenum pressure input terminals specified in 3.3.2.6 and measure the resulting output voltages across the specified output terminals. Check voltage gain and output voltage for conformance to 3.3.2.6. Repeat this test with 30.8 volts dc applied to the terminals specified in 3.3.1 and check for conformance to 3.3.2.6.

4.4.3 Environmental tests.

4.4.3.1 Nonoperating tests.- The Supply Signal Conditioner shall be subjected to the following nonoperating environmental tests to verify conformance to 3.4.1.

4.4.3.1.1 Temperature (transportation, handling, and storage).- Subject the Supply Signal Conditioner to a temperature of minus 22 plus or minus 4 degrees F for 3 hours. Raise the temperature to standard (see 4.3.1) and maintain until the temperature of the Supply Signal Conditioner does not vary more than 2 degrees F within 15 minutes, then raise the temperature to 140 plus or minus 4 degrees F and stabilize the temperature of the Supply Signal Conditioner as specified above. Return the temperature to standard and maintain until the Supply Signal Conditioner temperature is stabilized as specified above. Perform the tests of 4.4.1, 4.4.2.1, 4.4.2.2 and 4.4.2.3.

4.4.3.1.2 Shock.- Subject the Supply Signal Conditioner, through its mounting points, to the Method 516, Procedure IV shock test of MIL-STD-810, except that the peak intensity shall be 35g. Perform the tests of 4.4.1, 4.4.2.1, 4.4.2.2 and 4.4.2.3. (reference 3.4.1.b)

4.4.3.1.3 Vibration (sinusoidal).- Subject the Supply Signal Conditioner, through the normal mounting points or surfaces, to the sinusoidal vibration sweeps defined in Table II. Perform 1 sweep through each frequency range in each direction along the axis specified in the table at a sweep rate of 1 octave per minute. Perform the tests of 4.4.1, 4.4.2.1, 4.4.2.2 and 4.4.2.3. (reference 3.4.1.c)

4.4.3.1.4 Vibration (random noise).- Subject the Supply Signal Conditioner, through the normal mounting points or surfaces, to the random vibration specified in 3.4.1.d and Table III. Apply vibration of each spectral density for the duration shown, once along each of 3 mutually perpendicular axes. Perform the tests of 4.4.1, 4.4.2.1, 4.4.2.2 and 4.4.2.3. (reference 3.4.1.d)

4.4.3.2 Operating tests.- The Supply Signal Conditioner shall be subjected to the following operating environmental test to verify conformance to 3.4.2.

4.4.3.2.1 Thermal-vacuum.- Subject the Supply Signal Conditioner to a vacuum of less than 10^{-3} Torr. While in this vacuum, expose one side of the module for 6 hours to a radiation intensity of 1 solar constant (135 watts per square foot). During this environmental exposure, perform the test of 4.4.2 and maintain the operating duty cycle of 3.4.2.a. After this environmental exposure, perform the tests of 4.4.1 and 4.4.2. (reference 3.4.2.a)

4.4.4 Weight.- Weigh each Supply Signal Conditioner and check for conformance to 3.5.

4.4.5 Identification.- Examine each Supply Signal Conditioner for conformance to 3.6.

4.4.6 Workmanship.- Examine the Supply Signal Conditioner to make certain that the requirements of 3.7 are met.

4.5 Qualification testing.

4.5.1 Qualification test samples.- The qualification test samples shall consist of specimens representative of the production equipment. They shall be tested at a laboratory designated by the procuring activity. (see 6.3), or when so stated in the contract, at the contractor's plant under the supervision of the procuring activity.

4.5.2 Qualification tests.- Qualification tests shall include all tests specified under 4.4. Qualification testing shall be conducted only when and to the extent specified in the contract.

4.6 Preservation, packaging, and packing.- Inspection shall be sufficient to ensure that the requirements of Section 5 are met.

5. PREPARATION FOR DELIVERY

5.1 Preservation and packaging.- Preservation and packaging shall be Level A or C, as specifid by the procuring activity.

5.1.1 Level A.- Each Supply Signal Conditioner shall be packaged in accordance with Method IA-8 of MIL-P-116. Each module, with protective caps installed in accordance with 5.4, shall be wrapped in cushioning material conforming to PPP-C-843 to a minimum thickness of 1 inch on all sides. The module then shall be placed in a close fitting box conforming to Class 2 of PPP-B-566, PPP-B-636, or PPP-B-676.

5.1.2 Level C.- Each Supply Signal Conditioner shall be packaged as specified in 5.1.1, except that the packaging shall conform to Method III of MIL-P-116.

5.2 Packing.- Packing shall be Level A, B, or C, as specified by the procuring activity.

5.2.1 Level A.- The Supply Signal Conditioners, packaged as specified in 5.1.1 or 5.1.2, shall be packed in containers conforming to Class 2 of PPP-B-636, Class 2 of PPP-B-621, or PPP-B-601 (overseas type).

5.2.2 Level B.- The Supply Signal Conditioners, packaged as specified in 5.1.1 or 5.1.2, shall be packed in containers conforming to Class 1 of PPP-B-636, Class 1 of PPP-B-621, or PPP-B-601 (domestic type).

5.2.3 Level C.- The Supply Signal Conditioners, packaged as specified in 5.1.1 or 5.1.2, shall be packed in a manner that will ensure carrier acceptance and safe delivery at destination. Containers shall conform to Uniform Freight Classification Rules or to regulations of other carriers applicable to the mode of transportation.

q 5.3 Marking.- In addition to any special marking required by the contract or order, all interior and shipping containers shall be marked in accordance with MIL-STD-129.

5.4 Special handling.- When packaging the Supply Signal Conditioner, the protective caps shall be installed in accordance with Drawing 309229.

6. NOTES

6.1 Intended use.- The Supply Signal Conditioner covered by this specification is intended for use in the ATS-IV resistojet thrustor system as a power supply for transducers, to amplify sensor signals and supply readout voltages, and to supply a monitoring voltage for the control elements of a stable platform type satellite.

6.2 Ordering data.- Procurement documents should specify the following:

a. The title, number, and date of this specification.

b. Applicable stock number.

c. Serialization requirements.

d. The level of preservation, packaging, and packing.

e. Whether design qualification tests are required and the number of qualification test specimens to be submitted.

6.3 Procuring activity.- For the purpose of this specification, the procuring activity shall be defined as the National Aeronautics and Space Administration (NASA) or other Department of Defense Activity responsible for the Mod III contract.

REFERENCES

1. Avco/SSD, Final Report on Contract NAS 3-5908, entitled Resistojet Research and Development, Phase II, (June, 1966).

2. Avco/SSD, Final Report on Contract NAS 3-5908, entitled Resistojet Research and Development, Phase II, Supplement No. 1 (June 1966).

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